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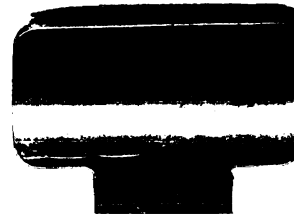

SAFETY-VALVES;

THEIR HISTORY, ANTECEDENTS, INVENTION AND CALCULATION.

INCLUDING

THE MOST RECENT EXAMPLES OF WEIGHTED AND SPRING LOADED VALVES.

ALSO,

SHOWING THE EFFECT OF ATMOSPHERIC PRESSURE ON SAFETY-VALVE DISKS;

SHOWING THE CURIOUS PHENOMENON OF BALLS BEING SUSTAINED BY AN INCLINED CURRENT OF AIR;

VACUUM VALVES AND THEIR IMPORTANCE IN HEATING AND BOILING.

BY

WILLIAM BARNET LE VAN,

Member of the Franklin Institute and the American Society of Mechanical Engineers.

Illustrated by Sixty-nine Engravings.

NORMAN W. HENLEY & CO.,
150 NASSAU ST., NEW YORK.
LONDON: E. & F. N. SPON.
1892.

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PREFACE.

In this book an attempt has been made to communicate in language free from technicalities, an explanation of the mechanical principles on which the operation of the Safety-Valve depends. Mathematics have been dispensed with as far as possible; the introduction of algebraical formulas in each case is followed by written rules. Formulas are best, as they not only tell what is to be done, but, at a glance, impress the mind with the complete operation. Those, however, who do not understand them can use the written rules.

The importance of having the general principles of Safety-Valves understood by those who are charged with the care of steam boilers, cannot well be over estimated.

The writer does not pretend to offer much that is original, or new, but has endeavored to collate from different authors, scientific periodicals and such publications that are not generally accessible, an explanation of the principle involved in the operation of Safety-Valves.

An endeavor has been made to present all of the known devices that are in use as well as those that have been projected and tested by persons who have given the matter careful study.

The writer is much indebted to many gentlemen for assistance and information which they have given him, and which will, where possible, be found to be acknowledged in the text. To the late Robert Briggs and John W. Nystrom, Richard H. Buel, Hugo Bilgram, and last, but not least, W. F. Durfee, the author feels that he is much indebted,

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2294 North Broad Street.

PHILADELPHIA, Feb. 10, 1892.

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SAFETY VALVES:

THEIR

History, Antecedents, Invention and Calculation.

The function of a safety valve, as used on a steam boiler, is to discharge steam so rapidly, when the pressure within the boiler reaches a fixed limit, that no important increase of pressure can then occur, however rapidly steam may be made. It should be so constructed and arranged, that should any accident occur, it may be opened by hand and the steam pressure lowered very rapidly, even when the grates are covered with a mass of incandescent fuel, and steam is being generated rapidly, without increasing the pressure in the boiler over 10 to 15 per cent above that to which the valve may be loaded.

The grate surface, all things considered, is the best unit of measurement for determining the size of safety valves. The ordinary rate of combustion runs from 10 to 15 pounds of coal per square foot of grate, and the rate of evaporation may be taken at 9 pounds of water per pound of coal as the maximum.

The higher the pressure the smaller the orifice will have to be; and, on the other hand, the lower the pressure the larger must the outlet be. A boiler in which the pressure does not exceed 40 pounds per square inch, may require from 30 to 40 square inches of area; while the same quantity of steam would escape through 4 square inches of area in a boiler carrying 150 pounds pressure.

A safety valve should not exceed 4 inches in diameter; when a valve of larger area than 4 inches is wanted, an extra safety valve should be added. The area of a valve increases nearly as the square of its diameter; the circumference, directly as the diameter. The

escape of the steam is around the circumference, and it will be understood, of course, that a point would soon be reached in which the area would be of little account if carried to large diameters and figuring on ordinary valves. For example, if the grate area required a common valve 6 inches in diameter, it would have a circumference of 18.84 inches; the same area would be furnished by two 3¼-inch valves, the combined circumferences of which would equal $9.621 \times 2 = 19.242$ inches.

As the safety valve is the main reliance in case of neglect or inattention of the engineer or fireman, it is important to carefully examine its mode of operation and the ordinary methods of construction and calculation for safety. However, before proceeding as above, we will endeavor to give the early history of the safety valve, as well as the antecedents, invention and the manner of proportioning and calculating all its parts. As this is a subject that has already been very carefully traversed, I do not pretend to offer much that is new or original, but will try to give that which will be the most useful, for the benefit of a portion of the rising generation, as well as for some others who may be interested, and in as simple language as is consistent with plainness; so that, any one who can solve simple equations in algebra, and who knows the simple definitions of trigonometry, and the elements of physics, shall understand it. Mathematics will be dispensed with as far as possible; but in each case, where possible, written rules, together with the particulars of working examples, will be given, so that the reader may study the subject for himself.

STEAM.

As the first result of the application of heat to a solid substance is to dilate it, and the next to melt it, so also the further application of heat converts it from a liquid into a vapor or gas. The point at which successive increments of heat, instead of raising the temperature, are absorbed in the generation of vapor, is called the "boiling point" of the liquid. Different liquids have different boil-

ing points under the same pressure, and the same liquid will boil at a lower temperature in a vacuum, or under a low pressure, than it will under a high pressure. As the pressure of the atmosphere varies at different altitudes, liquids will boil at different temperatures at different altitudes, and the hight of a mountain may be approximately determined by the temperature at which water boils at its summit.

DIFFERENCE BETWEEN GASES AND VAPORS.

Vapors are saturated gases, or, gases are vapors surcharged with heat. Ordinary steam is the saturated vapor of water, and if any of the heat be withdrawn from it, a portion of the water is necessarily precipitated. This is not so in the case of a gas under ordinary conditions. But if the gas be forced into a very small bulk, it will follow that any diminution of the temperature will cause a portion of the gas to condense into a liquid. Superheated steam resembles gas in its qualities, and a portion of the heat may be withdrawn from such steam without producing the precipitation of any part of its constituent water. (*Bourne.*)

Steam was among the motive agents of the most ancient idols of Egypt (as the statue of Memnon, and others), and some of the deified images of Europe; and it is curious to note that it should formerly have been employed with tremendous effect to delude men —to keep them in ignorance—while now it contributes so largely to enlighten and benefit mankind.

Steam has, of course, been noticed ever since the heating of water and cooking of food were practiced. The daily occurrence implied by the expression, "the pot boils over," was as common in antediluvian as in modern times; and hot water thus raised was one of the earliest observed facts connected with the evolution of vapor. From allusions in the most ancient writings, we may gather that the phenomena exhibited by steam were closely observed of old. Thus, Job, in describing Leviathan, alludes to the puffs, or volumes, that issue from under the covers of boiling vessels: "By his neesings a light doth shine, and his eyes are like the eyelids of the

morning; out of his nostrils goeth smoke [steam] as out of a seething pot or cauldron." In the early use of the vessels last named, and before experience had rendered the management of them easy and safe, women would naturally endeavor to prevent the savory contents of their pots from flying off in vapor; hence attempts to confine it by covers; and when these did not fit sufficiently close, a cloth, or some similar substance, interposed between it and the edge of the vessel, would readily suggest itself, and a stone or other weight placed upon the top to keep all tight would also be very natural. Then, as the fluid began again to escape, further efforts would be made to retain it by additional weights. In this manner, doubtless, many a contest was kept up between a pot and its owner till one gained the victory; and we need not the testimony of historians to determine which one this was. In those times it was not generally known that a boiling cauldron contained a spirit, impatient of control; that the vessel was the generator of an irresistible power, and the cover a *safety valve;* and that the preservation of the contents and the security of the operator depended upon letting the cover alone, or not overloading it; hence it no doubt often happened that the confined vapor threw out the contents with violence, and then it was that primitive cooks began to perceive that there was death as well as life in a boiling pot. In this manner, we suppose women were the first experimenters with steam (engineers), and the earliest witnesses of steam boiler explosions.

Ancient priests, both among the Jews and Gentiles, were, from their ordinary duties, necessarily conversant with the generation of steam. Its elastic force could not, therefore, escape the shrewd observers among them. Sacrifices were frequently *boiled* in huge cauldrons, several of which were permanently fixed in the vicinity of temples—in "boiling places," as their locations are named by Ezekiel, "where the ministers of the house shall boil the sacrifice of the people."

It would seem, moreover, as if some of the boilers

were made on the principle of Papin's digester, in which bones were softened by "high steam"; at any rate, a distinction is made between seething pots and cauldrons, and from the manner in which both are mentioned, they seem to have been designed for different purposes; the former to seethe or soften bones, the latter to boil the flesh in only. "They roasted the passover with fire, but the other offerings sod they in pots and in cauldrons," (ii. Cor. chap. 35, p. 13). "Set on a pot, set it on, and also pour water into it. Gather the pieces thereof into it, even every good piece, the thigh and the shoulder; fill it with the choice bones. Take the choice of the flock and burn (or heap) also the bones under it, and make it *boil well*, and let them *seeth the bones* of it therein." (Ezek. 24, p. 3, 5). The belief that the Jews had close vessels in which steam was raised higher than in common cauldrons, is also rendered probable from the fact that the Chinese, a contemporary people, employ similar ones, and which, from their tenacity to ancient devices, have probably been used by them from time anterior to those of the prophets. ("Davis' Chinese," ii. 271; "John Bell's Travels," i. 296, and ii. 13).

Some of the ancient philosophers, who were close observers of nature, compared the earth to a cauldron, in which water is heated by internal fires; and they explained the phenomena of earthquakes by the accumulation of steam in subterraneous caverns, until its elastic energy rends the superincumbent strata for a vent. Vitruvius explains by it the existence of boiling springs. In the reign of Justinian, Anthemius, an architect and mathematician, illustrated several natural phenomena by it; but of this we should probably never have heard had it not been for a quarrel between him and his next-door neighbor, Zeno, the rhetorician. This orator appears to have inherited a considerable share of credulity and superstition, which gave his antagonist the advantage. Anthemius, we are informed, had several steam boilers in the lower part of his house, from each of which a pipe conveyed the vapor above, and by some

mechanism, of which no account has been preserved, he shook the house of his enemy as by a real earthquake, upon which the affrighted Zeno rushed to the Senate, "and declared in a tragic style that a mere mortal must yield to the power of an antagonist who shook the earth with the trident of Neptune."

The boiler engineer of to-day, noting the curious things in bronze and in copper exhumed at Pompeii, and gathered together in the Museo Borbonico, at Naples, will linger near a small vessel for heating water, little more than a foot high, in which are combined nearly all the principles involved in the modern vertical steam boiler—fire box, smoke flue through the top, and fire door at the side, all complete; and, strange to say, this little thing has a *water grate*, made of some small tubes crossing the fire-box at the bottom, an idea that has been patented twenty times over, in one shape or another, within the period of the history of the steam boiler.

The boilers of the fast boats built by the Herreshoff Company, of Bristol, R. I., are similar in construction to those found in the Thermae at Pompeii, taken from impressions left in the mortar or cement in which they were embedded. Some idea of the capacity of these boilers may be derived from the fact that a single establishment could accommodate *two thousand persons* with warm, or rather *hot*, baths at the same time. Seneca, in a letter to Lucilius, says "there is no difference between the heat of the baths and a *boiling furnace*"; and it would, he observes, appear to a reasonable man as a sufficient punishment to wash a condemned criminal in them. The persons who had the charge of heating in close vessels and distributing daily such large quantities of water, must necessarily have been conversant with the mechanical properties of steam, and the economical modes of generating it.

VALVES.

The bellows was probably the first instrument of which they formed a part. No other machine equally ancient can be pointed out in which they were required. That the bellows is of antediluvian origin,

there can be little doubt, for neither Tubal-Cain nor any of his pupils could have reduced and wrought iron without it.

Strabo attributed the bellows to Anacharsis, who lived about 600 years B. C. Pliny (B. vii., 56), attributes it to the fabled Cyclops of Greek mythology. The prophet Jeremiah, who lived long before Anacharsis, speaks of it in connection with metallurgical operations: "The bellows are burned, the lead is consumed of the fire; the founder melteth in vain." Isaiah, who lived still earlier, namely, in the eighth century B. C., alludes to the blacksmith's bellows: "The smith that bloweth the coals in the fire." Job, nine or ten centuries before the Scythian philosopher flourished, speaks of the blast furnace as common: "They gather silver, and brass, and iron, and lead, and tin, into the midst of the furnace, to *blow the fire* upon it to melt it." Homer, as might be supposed, could not fully describe the labor of Vulcan without referring to this instrument. His account of the great mechanical work is equally descriptive of a smith and his forge of the present day.

> "Obscure in smoke, his forges flaming round,
> While bathed in sweat from fire he flew,
> And puffing loud, the roaring bellows blew.
> . . . . . .
> Just as the gods direct, now loud, now low,
> They raise a tempest, or they gently blow."
> [*Iliad*, xviii., 435, 545. *Pope.*

The most important improvement on the primitive bellows, or bag, was the admission of air by a *separate* opening—a contrivance that led to the invention of the *valve*, one of the most essential elements of steam or water, as well as pneumatic, machinery. The first approach to the ordinary valve, was a device that is still common in the bellows of some African tribes. A bag formed of the skin of a goat, has a reed attached to it to convey the blast to the fire, and the part which covered the neck of the animal is left open for the admission of air. This part is *gathered up* in the hand when the bag is compressed, and opened when it is distended. (Ewbank's Hydraulics, 235).

The principle of the *valve* has always been in use for a variety of purposes. Doors are *valves*, and were so named by the ancients. Those of the private apartments of Juno were contrived by Vulcan to close of themselves. Thus, Homer sings:

"Touched with the secret key, the doors unfold,
Self-closed behind her shuts the valve of gold."

[*Iliad*, xiv.

It is probable that all valves were originally in the form of doors; that is, mere flaps or clacks moving on a hinge, and either lying horizontally, like a trap-door; inclined, like some of our cellar doors; opening vertically, as an ordinary door; or suspended by hinges, from the upper edge; and sometimes they consisted of two leaves like folding doors. Examples of all these are still common. Isis was represented by the ancient Egyptians with "the key of the sluices of the Nile" in her hand, the instrument by which the doors or valves, like the locks in our canals were opened and closed,

The most ancient musical wind instruments known in the Eastern world are provided with valves, as the primitive bag-pipes, and the Chinese variation of this instrument, which Toreen describes as consisting of "a hemisphere to which thirteen or fourteen pipes are applied, and catching the air blown into it by valves." The pastoral flute of Pan, from its expressing thirty-two parts, he supposes to have been of a similar construction, (Osbeck's Voyage, ii. 248). Valves were, of course, employed in the organs of Jubal, as well as in the bellows belonging to his celebrated brother, and other antediluvian blacksmiths. The ninth problem of the *Spiritalia* relates to valves. Conical metallic valves were used by Ctesibius, of Alexandria, one of the most eminent mathematicians and mechanicians of antiquity, in the construction of *clepsydræ*. (Instruments used by the Greeks and Romans, for measuring time by the gradual discharge of water from a large vessel through a minute perforation in the bottom).

The spindle valve, or such as have a long shank

to prevent their rising too high, and guiding them when descending, is said to be of French origin.

EARLY SAFETY VALVES.

The liability of alembics and stills to burst, led the old chemists to apply plugs to the openings in these vessels, that the vapor might raise or drive them out and escape ere the pressure exceeded the strength of the vessels. In old works on distilling, conical plugs, or valves, are shown as fitted into cavities on the tops of boilers, and, in some cases, they were loaded. In the *Maison Rustique de Maistres Charles Estienne et Jean Liebault, Docteurs en Médécine* (Paris, 1574), are figures of two *close* boilers, in which the distilling vessels were heated; one formed a water, and the other a vapor, bath. On the top of each is a conical valve, opening upwards. These served both to let out the superfluous steam and to introduce water. Glauber, who contributed several valuable additions to the mechanical department of chemistry, has figured and described, in his "Treatise on Philosophical Furnaces," the modes by which he prevented glass retorts or stills from being burst by the vapor. A long stopple, or conical valve, was fitted to the neck of each, being ground air-tight to its seat, and loaded with a "cap of lead," so that, when the steam became "high," it slightly raised the valve, and a portion escaped. The valve then closed again of itself, "being pressed down with the leaden cap, and so stopped close." (English translation, London, 1651, page 306). The safety valve on Newcomen's first engine was of this description.

The above safety valve is now known as a "positive safety valve," the valve as now made being flat, conical, or spherical, thus exposing a greatly increased area when opened. This is a meritorious feature, as the experiments of Baldwin, Richardson, Adams, and numerous safety-valve makers have proven. In these, the weight is either placed directly above or below the valve, and acts without the aid of levers.

In the same work, Glauber describes the most philosophical of all safety valves—namely, a column

of mercury enclosed in a bent tube, which communicates with the boiler or still, somewhat like the modern mercurial gauge. He also describes that beautiful modification of it known among chemists as the "water lute," or "quicksilver lute," which is made as follows: Around the mouth or neck of a vessel, a deep cavity is formed and partly filled with water or mercury, as the case may be. A cylindrical vessel, open at the top and closed at the bottom, forms the cover; it is inverted, the open end being placed in the cavity and dipping as far into the liquid as the internal pressure may require. In "The Art of Distillation ; or, A Treatise of the Choicest Spagyrical experiments," etc., by John French, Doctor of Physic, London, 1651, the author describes the same devices for preventing the explosion of vessels as those mentioned by Glauber. Speaking of the action of such safety valves, he observes (page 7): "Upon the top of a stopple [valve] there may be fastened some lead, that if the spirit be too strong, it will only heave up the stopple and let it fall down again."

LEVER SAFETY VALVE.

The common lever safety valve was invented by a Frenchman, Solomon Decaus, and was improved by Denis Papin. Through the influence of the celebrated Boyle, whom he assisted in his experiments with the air pump, Papin was elected a Fellow of the British Royal Society in December, 1680. He was an active and useful member, and contributed several interesting papers to the society's transactions. In 1681 he invented a method of softening bones, with a view to extract nourishing food from them—namely, by submitting them to the action of steam at high temperatures (pressure), in close vessels named *digesters*.

Papin's first digesters were liable to be rent asunder by the high pressure of steam accumulating in them when in place on the fire with their orifices stopped. They are shown in detail in Poliniere's "Experience de Physique," second edition, Paris, 1718. Each consisted of a short but very thick tube, of bell metal, about a foot in length and five inches

in diameter, with one end closed. The open end had a collar cast on it, to which the cap or cover was secured by clamps and a screw. The cover and end of the tube were ground together, so as to fit air-tight, like a valve to its seat. A few bones and a little water were put in, and the cover screwed down; the vessel was then laid in a horizontal position on a bed of charcoal in a long iron grate. The almost unavoidable rupture of these vessels, led Papin to the invention of the common lever safety valve, which he first applied to them, and afterwards to machines for raising water by steam.

It is due to Papin to state, that no one whose labors have produced so many important results, has in his writings shown so little of the vanity and absurd enthusiasm proverbially characteristic of an inventor. He is considered by his countrymen to be the true inventor of the steam engine, a claim strongly contested by some English authors of eminence who have written on the subject. The claim of his countrymen is based on communications by Papin to the *Acta Eruditorum* of Leipsig, in 1685. One of these is a description of a new machine to raise water, which is further noticed in the same journal in June, and again in the August following; and in the *Nouvelles de la Republique des Lettres* for July, 1687, is a reply by Papin to some objection raised against this apparatus by M. Nuit.

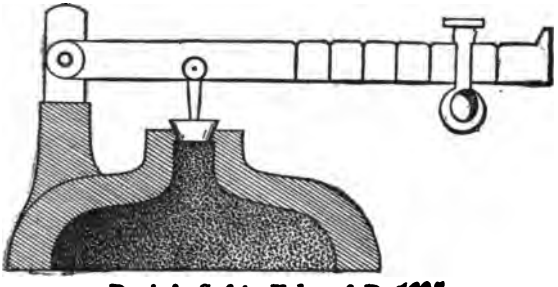
In 1687 Papin was appointed Professor of Mathematics at Marburg, in Germany.

Papin's claim to the invention of the safety valve, therefore, is not to the valve itself, but to the mode of applying it by means of a lever and movable weight, thereby not only preventing the valve from being blown entirely out of its place, but regulating the pressure at will, and rendering the device of universal application.

His safety valve consists of a conical valve, retained in its sit by a weight on a lever; and from its resemblance to a steelyard, was called the "steelyard safety valve."

The ordinary commercial safety valve, as now

made, is a disk with a beveled edge, resting on a corresponding sit. The disk is kept down against the pressure in the boiler by external pressure variously applied, either by a weight acting with a leverage, or by a spring. This opening for the efflux of steam, created by the rise of the valve, is thus an annular opening. The opening through the valve must be understood to be the *effective* opening clear of bridges or other obstacles, and the area to be computed is the area of the smallest diameter of the



Papin's Safety Valve, A.D. 1695.

valve. As before stated, the valve is chamfered on the edge, which edge constitutes the steam-tight surface, and the effective area is what corresponds to the smaller diameter of the valve seat and not to the larger.

All boilers should have an extra or additional safety valve, of the same capacity as the other, which may act in case of accident to the first from getting jammed, or otherwise. When there are more than one boiler, a pair of safety valves in such a case must be put on each boiler.

Weighted safety valves are never employed on locomotives, and but seldom on steamships, as much steam is liable to escape during the oscillatory motions of the ship. Every safety valve should be so located that it can be opened by hand at least twice each day; or, if not convenient to so place it, a cord should be secured to the lever or stem of the valve so as to operate it as above, to keep the valve free and in good working order.

The subject of safety valves is wholly embraced in the static branch of mechanics.

STATICS.

Statics is the science of force in equilibrium, or at rest. It embraces the strength of materials, of bridges and of girders; the stability of walls, chimneys, steeples and towers; the static momentum of levers, with their combinations into weighing scales, windlasses, pulleys, funicular machines, inclined planes, screws, catenaria, and all kinds of gearing.

FORCE.

The term *force* means any action which can be expressed simply by weight, and which can be realized

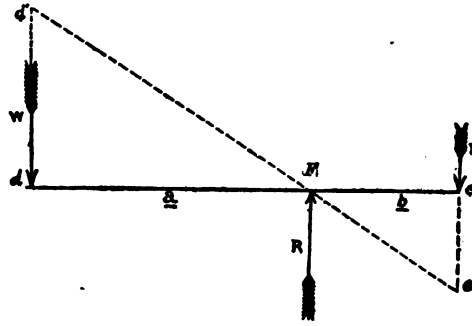


Fig. 2.

only by an equal amount of reaction. Force is derived from a great variety of sources; but whenever it is simply force, it can invariably be expressed by weight, without regard to motion, time, power or work. The magnitude and direction of a force can be represented by a straight line; but no force can be realized without an equal amount of resistance in the opposite direction, which likewise can be represented by a straight line.

To illustrate: Let it be proposed to find the result-

ant of two parallel forces F and W, acting at the ends of an inflexible line *d e*.

Prolong the line W until *d d'* is equal to F, prolong F until *e e* is equal to W, then join *d'* and *e'*, which will cut the inflexible line at *f*. Draw from *f*

PROBLEM I.

the resultant R, equal and parallel to W+F; then R represents the magnitude and direction of the resistance which balances the two forces F and W. The distance $a=d\,f$ is the lever for the force W, and $b=f\,e$ is the lever for F, which quantities bear the following relation:

F : W=*a* : *b*, static momentums W *a*=F *b*.

STATIC MOMENTUM.

The product of a force multiplied by its lever is called *static momentum*. The resistance at *f* is called the *fulcrum*. It is supposed in this case that the forces W F act at right angles to the levers *a* and *b*. The lever of any force is equal to the right angular distance from the fulcrum to the direction of that force. When the static momentums W *a* and F *b* are equal, then the forces W and F are in equilibrium.

LEVERS.

Levers are classified into three different kinds with reference to the relative position of the force F, weight W, and fulcrum *f*.

When the fulcrum *f* is between the force F and weight W, the lever is called the lever of the *first order* (Fig. 3).

When the weight W is between the force F and the fulcrum *f*, the lever is of the *second order* (Fig. 4).

When the force F is between the weight W and the fulcrum *f*, the lever is of the *third order* (Fig. 5).

The two forces F and W will be distinguished by considering F the applied force, acting on its lever L, to lift the weight W, acting on its lever *l*.

Algebraical and Geometrical expressions of the Fundamental Principles of Statics of Levers of different kinds.

PROBLEM II.

First Order.

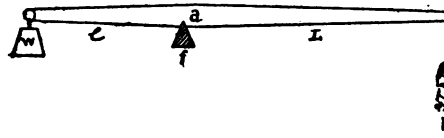


Fig. 3.

$$F : W = l : L, \text{ or } F\,L = W\,l$$

$$F = \frac{W\,l}{L} \qquad W = \frac{F\,L}{l}$$

$$l = \frac{F\,a}{W+F} \qquad L = \frac{W\,a}{W+F}$$

PROBLEM III.

Second Order.

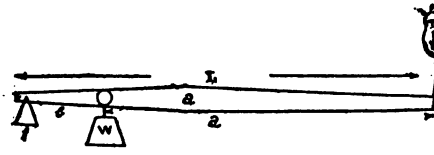


Fig. 4.

$$F : W = l : L, \text{ or } F\,L = W\,l$$

$$F = \frac{W\,l}{L} \qquad W = \frac{F\,L}{l}$$

$$l = \frac{F\,a}{W-F} \qquad L = \frac{W\,a}{W-F}$$

PROBLEM IV.

Third Order.

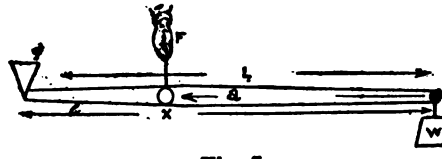


Fig. 5.

$$F : W = l : L, \text{ or } F\,L = W\,l$$

$$F = \frac{W\,l}{L} \qquad W = \frac{F\,L}{l}$$

$$l = \frac{F\,a}{F - W} \qquad L = \frac{W\,a}{F - W}$$

This latter is the lever that is common to all safety valves now in general use on steam boilers.

CENTER OF GRAVITY.

The center of gravity of a body, or of a rigid system of bodies, is a point in which, if they were suspended, the body will be in equilibrium in any posision, like that of a wheel or circle-plane suspended in the center.

A body suspended freely from any point *h*, will hang with its center of gravity in the vertical line

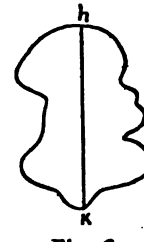


Fig. 6.

h k. Now suspend the body from another point *s*, and the center of gravity will be on the line *s m*; then when the center of gravity is on both the lines

p o and *s m*, it must evidently be at *g*, where the two lines cross one another (see Figs. 6 and 7).

The lines *p o* and *s m*, or the center of gravity *g*, can also be found by balancing the body on a sharp edge. The center of gravity of any figure or body

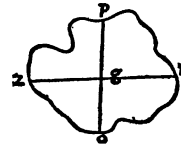


Fig. 7.

is thus found by suspending or balancing the same in two different positions.

PROBLEM V.

In the foregoing (Figs. 3, 4 and 5), we have considered the levers to be inflexible lines without weight, which will answer when the center of gravity of the material levers is in the fulcrum, like that of a weighing balance, or that of a wheel; but this center of gravity is often located at a considerable distance from the fulcrum, as may be illustrated by Fig. 8, which is a lever of the first order, Fig. 3. The levers

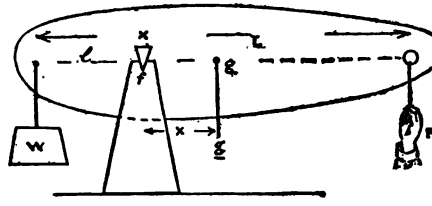


Fig. 8.

l and L are in the form of a beam resting on the fulcrum *f*, and its center of gravity at *g*. Let the weights of the beam be represented by *g*, acting on the lever *x*; there will be two static momentums F L and *g x*, on one side of the fulcrum, against one W *l*, on the other side.

$$W\,l = F\,L + g\,x \qquad F\,L = W\,l - g\,x$$

$$g\,x = W\,l - F\,L \qquad W = F\,L + g\,x$$

$$F = W\,l - g\,x \qquad g = W\,l - F\,L$$

$$l = \frac{F\,L + g\,l}{W} \qquad L = \frac{W\,l - g\,x}{F}$$

$$x = \frac{W\,l - F\,L}{g}$$

PROBLEM VI.

Fig. 9 is a lever of the third order, representing a safety valve as made and sold commercially.

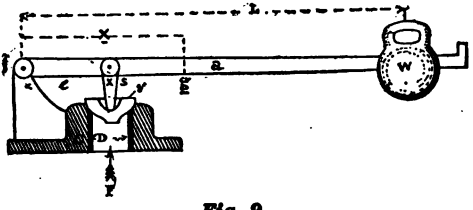


Fig. 9.

$$F\,l = W\,L + g\,x$$

$$W\,L = F\,l - g\,x \qquad W = \frac{F\,l - g\,x}{L}$$

$$g\,x = F\,l - W\,L$$

$$F = \frac{W\,L + g\,x}{l} \qquad g = \frac{F\,l - W\,L}{x}$$

$$x = \frac{F\,L - W\,L}{g} \qquad l = \frac{W\,L + g\,x}{F}$$

$$L = \frac{F\,l - g\,x}{W}$$

The formulas above are the same as those for the lever of the second order (Fig. 8).

The center of gravity g may be found experimentally by balancing the beam over a sharp edge, when the distance x can be measured from the fulcrum f. It is here supposed that the levers l and L are in a straight and horizontal line. The form of the beam affects the location of the center of gravity g, as shown in Fig. 9; but when this center is known, the shape of the beam does not affect the static momen-

tums. The pressure on the fulcrum f is equal to $W+g-F$.

Fig. 10 will better show the different functions of a safety valve when in service on a boiler under steam pressure.

A safety valve consists, primarily, of a movable disk, ring or plate, held from without, in the majority of cases, by a weight or a spring, over an orifice in a containing vessel against the pressure of a fluid within, so that it will resist any required pressure to which it may be adjusted, at the same time that any greater pressure will move it away from its seat and permit some of the contained fluid to escape. In the case of a steam safety valve, the contained fluid is steam in contact with water; the containing vessel is a steam boiler and the chambers and pipes in unobstructed communication therewith; and the office of the safety valve is to discharge all the steam which may at any time be generated within the boiler in excess of the steam drawn from it, after a certain pre-determined limit of pressure has been reached. Safety valves are generally circular or annular plates of brass or iron, with corresponding seats; and, omitting as irrelevant many special forms, are of two classes:

First. Those which are held to their seats against internal pressure by weights, either acting directly or through levers; in most general use with stationary boilers.

Second. Those which are held to their seats against internal pressure by springs, either acting directly or through levers; used almost exclusively upon locomotives, and to a great extent on portable steam engine boilers.

The form of safety valves in general use to-day, as before stated, were used by Papin in 1680, and are, therefore, two hundred years old, and probably much older.

If the contact between a safety valve and its seat were the contact of two sharp edges, like two circular knives edge to edge, the action of a valve in opening and closing would be simpler than it can generally be in practice. In fact, the surface in contact

must have, for constructive reasons, a breadth very considerable in proportion to the diameter of the orifice closed by the valve; and since the areas of circles are to each other as the squares of their diameters, the area of the circle circumscribed by the outer border of the valve seat is materially larger than the area bounded by the inner border of the seat. The smaller area alone, within the seat, is acted on by the confined steam while the valve is closed; the larger area, within the outer border of the seat, is acted on by the escaping steam while the valve is open. It was, therefore, not unnatural to suppose that a safety valve, once opened against a resistance nearly constant, would immediately open still more widely, so as to give free outlet to the steam; and that it would remain open until a very sensible reduction of pressure in the boiler should enable a force, at first overcome by the higher pressure on the smaller area, to overcome in its turn the reduced pressure on the larger area.

That the reverse is true is well known. A safety valve, opened so as to permit the escape of a thin film of steam, can be further lifted so as to permit the free escape of steam, only by considerable increase of pressure, or by some special contrivance. It is usual to explain this phenomenon entirely by the increased resistance of springs due to increased tension; but this cannot be the sole cause, since the same thing is observed in a less degree where weights are used to close the valve. An additional cause is to be found in the expansion of a film of escaping steam between the valve and its seat, as in the familiar "pneumatic paradox" described by Bourne as "the tendency which escaping steam has to suck the valve down." There is also a little sluggishness and hesitancy about a movement produced by a very slight preponderence of nearly balanced forces. All motion is attended with some friction and some inertia; and decided preponderance is required to produce decided movement. To counteract this inertness, and to give promptness and decision—in a word, to give "pop!" to the action of a safety valve,

both in opening and in closing, many expedients have been invented, and will be described further on.

Reference being had to Fig. 10, the letters denote as follows:

1. D represents the diameter of the valve chamber C, also the smallest point of contact of the valve *v*.
2. W represents the weight acting on the long lever L.
3. *w* represents the weight of the lever arm *a*, valve *v*, and stem *s*, acting on the lever *w*.

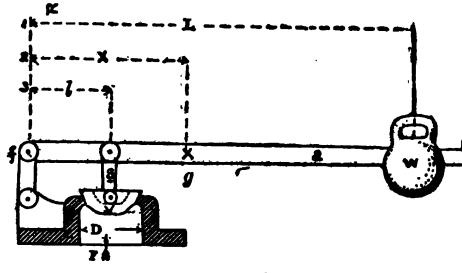


Fig. 10.

4. L represents the long lever, and is the distance from the center of the weight W, to the fulcrum *f*, on which the lever arm *a* rests.
5. *l* represents the short lever, and is the distance from the center of the valve stem *s* to the fulcrum *f*.
6. *x* represents the distance from the center of gravity *g*, to fulcrum *f*.
7. *f* represents the fulcrum, and is the support on which the lever arm *a* rests.
8. *a* represents the lever arm, on which is placed the weight W, and to which is attached the valve stem *s*.
9. *v* represents the valve covering the chamber C.
10. *s* represents the valve stem, or guide, of valve *v*.
11. *g* represents the center of gravity of the lever arm *a*, valve *v*, and stem *s*.
12. *p* represents the steam pressure above that of atmosphere (as shown by the steam gauge).

mainder by the length of the long lever L, and the quotient will be the weight W in pounds required.

To find the length of the long lever L, the area A of the valve, the steam pressure p, and all the other dimensions being known:

$$\text{Lever } L = \frac{A\,p\,l - w\,x}{W} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ 3$$

Rule.—Subtract the momentum $w\,x$ of the lever arm a from the area A of the valve in square inches, multiplied by the steam pressure p in pounds per square inch, and this product by the length of the short arm l, and divide this remainder by the weight W in pounds; the quotient will be the distance in inches from fulcrum f to place the weight W.

To find the pressure p per square inch at which a safety valve will blow off, the weight W, and all the other dimensions being known:

$$\text{Pressure } p = \frac{W\,L + w\,x}{A\,l} \quad \ldots\ldots\ldots\ldots\ldots\ 4$$

Rule.—To the momentum of the lever arm a, add the product of the weight W, multiplied by the length of the lever arm L; divide this sum by the product of the area A, multiplied by the length of the short lever l, and this quotient will be the steam pressure p in pounds per square inch.

To find the area A in square inches, the weight W, and steam pressure p, and all the other dimensions being known:

$$\text{Area } A = \frac{W\,L + w\,x}{p\,l} \quad \ldots\ldots\ldots\ldots\ldots\ 5$$

Rule.—To the momentum $w\,x$, of the lever arm a, add the product of the weight W, multiplied by the length in inches of the lever L; this sum, divided by the product of the steam pressure p in pounds per square inch by the length of the short lever l, will be the area A in square inches.

To find the weight w of the lever arm a, valve and stem s, the area A in square inches, and steam pressure p, and all the other dimensions being known:

$$\text{Weight of lever } w = \frac{A\,p\,l - W\,L}{x} \quad \ldots\ldots 6$$

Rule.—Subtract the product of the weight W, multiplied by the length of lever L, from the product of the area A multiplied by the steam pressure p, and this product by the length of the short lever l; this remainder, divided by the lever x, or distance of the center of gravity g from fulcrum f, the quotient will be the weight of lever a, and valve v and stem s.

To find the distance x in inches from the center of gravity g to fulcrum f, the area A in square inches, of the valve, the steam pressure p in pounds per square inch, and all the other dimensions being given:

$$\text{Distance } x = \frac{A\,p\,l - W\,L}{w} \quad \ldots\ldots 7$$

Rule.—Multiply the weight W by the length of the lever L; from this product subtract the product of the area A, multiplied by the steam pressure p, and this product by the length of lever l; divide this remainder by the weight w, of the lever arm a, valve v, and stem s.

Having given the levers L, l, and x the area A ($D^2 \times 0.7854$), steam pressure p, and the weight w, the weight W is calculated by formula 2.

Example 2.—A safety valve has a diameter of D=2 inches, and the lever to a pressure of steam p=80 pounds per square inch, with the following dimensions:

A=area of valve D=2 inches ($2 \times 2 \times 0.7854$) 3.1416
L=long lever in inches.....30
l=short lever in inches..... 4
x=distance of center of gravity g.....15
w=weight in pounds of lever arm a, valve v, and stem s..... 6
p=steam pressure per square inch in pounds.80

What will be the weight required?

$$\text{Formula 2: } W = \frac{A\,p\,l - w\,x}{L}$$

$$W=\frac{3.1416\times80\times4-6\times15}{30}=80.5 \text{ pounds.}$$

Example 3.—Suppose a safety valve to be of the following dimensions, at what distance L from the fulcrum f must the weight W be placed to carry a steam pressure p—50 pounds per square inch?

A=area of valve D—3 inches (3×3×0.7854).. 7.068
p=steam pressure per square inch in pounds. 50
l=short lever in inches..... 4
w=weight of lever arm a, valve v, and stem s in pounds.....10
x=distance of center of gravity g in inches..18
W=weight in pounds.....50

$$\text{Formula 3: } L=\frac{A\,p\,l-w\,x}{W}$$

$$\text{Lever L}=\frac{7.068\times50\times4-10\times18}{50}=22.6 \text{ inches.}$$

Example 4.—A safety valve having the following dimensions, at what pressure p per square inch will it blow off?

L=length of long lever in inches.....80
l=length of short lever in inches..... 8
W=weight in pounds.....50
w=weight of lever arm a, valve v, and stem s...12
x=length from fulcrum f to center of gravity g, in inches.....15
A=area of valve in square inches 7

$$\text{Formula 4: } p=\frac{W\,L+w\,x}{A\,l}$$

$$\text{Steam pressure } p=\frac{50\times80+12\times15}{7\times8}=80 \text{ pounds.}$$

Example 5.—The following dimensions, and the steam pressure p per square inch to be carried, to find the area of valve A?

L=length of long lever in inches..... ...80
l=length of short lever in inches..... 4
W=weight in pounds.....80

w=weight of lever arm a, valve v, and stem s, in pounds.....12
x=distance from fulcrum f to center of gravity g in inches.....10
p=steam pressure in pounds per square inch....40

Formula 5: $A=\frac{W L+w x}{p l}$

Area $A=\frac{30\times30+12\times10}{40\times4}=6.375$ square inches.

or about $2\frac{7}{8}$ inches in diameter.

Example 6.—A safety valve of the following dimensions, to find the weight of the lever arm a, valve v, and stem s, the distance x and steam pressure p being given.

A=area of valve in square inches..... 2
p=steam pressure in pounds per square inch..80
L=length of long lever in inches.....20
l=length of short lever in inches..... 1.5
W=weight in pounds.....10
x=distance from center of gravity g to fulcrum f in inches.....10

Formula 6: $w=\frac{A p l-W L}{x}$

Weight $w=\frac{2\times80\times1.5-10\times20}{10}=4$ pounds.

Example 7.—A safety valve of known dimensions, given to find the distance x from center of gravity g to fulcrum f, in inches.

A=area of valve in square inches.....20
p=steam pressure in square inches.....80
L=length of long lever in inches.....40
l=length of short lever in inches..... 4
W=weight in pounds.....50
w=weight of lever arm a, valve v and stem s in pounds.....20

Formula 7: $x=\frac{A p l-W L}{w}$

Distance $x=\frac{20\times80\times4-50\times40}{20}=20$ inches.

THE GRADUATION OF SAFETY VALVE LEVERS.

For great accuracy in finding the center of gravity g, the weight of valve v and stem s should be weighed with the lever arm a; and they also should be placed on the lever at their proper distance from fulcrum f when the lever arm a is balanced over a sharp edge. As before stated, the momentum $w\,x$ of the lever is found by multiplying the weight of lever arm a, valve v and stem s by the distance x from the fulcrum f to the center of gravity g, which is a constant quantity in the graduation of the lever for different pressures of steam.

Example 8.—A safety valve of the following dimensions, the lever to be graduated from 30 to 80 pounds to the square inch.

First find the weight W required for a steam pressure of 80 pounds to the square inch, which number is to be marked on the lever 30 inches from the fulcrum f.

A=area of valve in square inches..... 3
p=steam pressure in pounds per square inch..80
L=length of long lever in inches.....30
l=length of short lever in inches..... 2
w=weight of lever arm a, valve v and stem s in pounds..... 4
x=distance from fulcrum f to center of gravity g in inches 7.5

$$\text{Formula 2: } W=\frac{A\,p\,l-w\,x}{L}$$

$$\text{Weight } W=\frac{3\times80\times2-4\times7.5}{30}=15 \text{ pounds.}$$

The weight W required to balance steam pressure p=80 pounds to be placed on the lever L—30 inches from the fulcrum f.

Now find the long lever L, or at what distance from fulcrum f shall the weight W—15 pounds be placed to balance a steam pressure of p—80 pounds to the square inch.

$$\text{Formula 3: } L=\frac{A\,p\,l-w\,x}{W}$$

$$\text{Dist. from fulcrum } f\text{—L} = \frac{8\times80\times2-4\times7.5}{W} = 10 \text{ ins.}$$

Then measure off this distance L—10 inches on the lever arm *a* from the fulcrum *f*, and mark it with the number 80; divide the distance between the first and second positions of the weight into 80—30—50 equal parts, and number them from 30 to 80 consecutively. The lever is thus graduated for the required pressure of steam by 1 pound of difference per square inch.

The following method of calculating the weight area of safety valves is used by Morris, Tasker & Co., incorporated, of Philadelphia, furnished them by the late Robert Briggs (see Fig. 11).

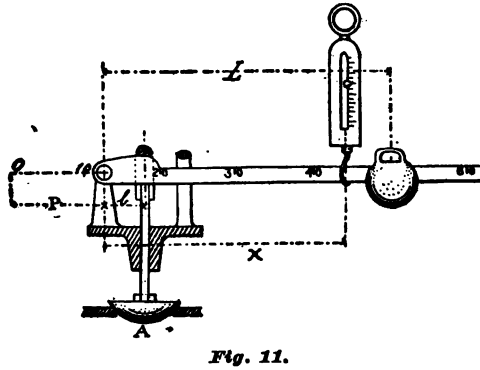


Fig. 11.

First. Multiply the area A of the valve *v* in square inches ($0.7854\ D^2$) by 10 pounds (or whatever unit of pressure per square inch is taken to form a division of the lever).

Second. Multiply the short lever *l*, in inches, by the area A in square inches and the 10 pounds (the divisions of the lever), which will give 10 A *l*, which will equal the *momentum* of the pressure on the valve at 10 pounds pressure *p*, per square inch on the short lever *l*.

Third. Divide the momentum 10 A *l* by the weight W, having assumed a weight W which it is desirable

to use; the result is the length in inches of each division of the lever, which will indicate 10 pounds pressure p per square inch on the valve surface.

Fourth. Remove the weight W from the lever arm, hook on a spring balance at some ascertained distance x, in inches from the fulcrum f, and lift the lever arm, valve v, and spindle s from its sit by the balance. Take the weight w indicated and multiply it by the distance x, and the result will be the *momentum* of the weight W, and the result will give the length of an imaginary line P, behind the fulcrum f, on the end of which if the weight W were hung it would balance the lever arm, valve v, and spindle s.

Fifth. The end of the line P, we will call 0=zero, as a new point from which the first division commences, and the following divisions are to be carried along the lever arm, as shown on the drawing.

The algebraical expression of the above rule may be set up as follows:

Let 0=zero point of lever arm.

L=long lever in inches.

l=short lever in inches.

x=equal distance from fulcrum f at which the spring balance is applied.

W=weight in pounds.

w=weight indicated by spring balance.

A=area of valve v in square inches ($0.7854\ D^2$).

$$\text{Divisions of 10 pounds each} = \frac{10\ A\ l}{W} \quad \ldots\ldots\ldots\ldots 8$$

$$\left.\begin{array}{l}\text{Distance of zero point behind}\\ \text{fulcrum } f\text{, to balance lever}\\ \text{arm, valve } v\text{, and stem } s.\end{array}\right\} = \frac{w\ x}{W} \quad \ldots\ldots\ldots\ldots 9$$

Practically, the pressure a safety valve lever exerts on the valve v can be ascertained by fixing it in its place, and securing the valve and stem in its proper position, and attaching a spring balance to the lever arm immediately over the center of the valve v. If the weight W be also attached, in lifting the valve slightly the balance will indicate the total pressure

which tends to keep the valve in its sit, which pressure being divided by the number of square inches in the valve area A, will give the pressure p per square inch at which steam will commence to blow off.

Example 8.—A safety valve having a diameter of 2.5 inches, its area A will be 4.908 square inches ($0.7854 \times 2.5 \times 2.5 = 4.908$). Now, in raising the lever arm a, valve v, stem s, and weight W, attached the spring balance indicates 245 pounds, the pressure at which the valve will lift is the quotient arising from dividing this 245 pounds by the area A of the valve —4.908 square inches.

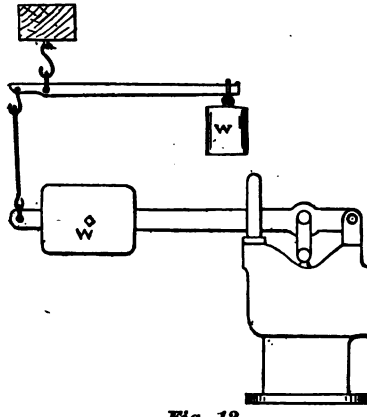


Fig. 12.

$$p = \frac{245}{4.908} = 50 \text{ pounds pressure per square inch.}$$

The pressure exerted by a safety-valve lever can be arrived at with a common steelyard, as shown in Fig. 12.

SAFETY VALVES WITH BALANCED LEVERS.

Safety-valve levers are sometimes prolonged beyond the fulcrum f, and provided with an adjustable weight W, which is set to balance the weight of the lever arm a, valve v, and stem s, as shown in Fig. 13.

This manner of making safety valves simplifies the calculation very much.

The algebraical expression of these values may be set up as follows:

$$W\,L = A\,p\,l \quad \ldots\ldots 10$$

Rule.—The weight W, multiplied by the length of the long lever L, equals the area A of the valve v, multiplied by the steam pressure p per square inch, and this product by the length of the short lever l.

$$\text{Weight } W = \frac{A\,p\,l}{L} \quad \ldots\ldots 11$$

Rule.—Multiply the area A by the steam pressure p, per square inch, and this product by the length of the short lever l, and divide this last result by the length of the long lever L; the quotient will be the weight W in pounds.

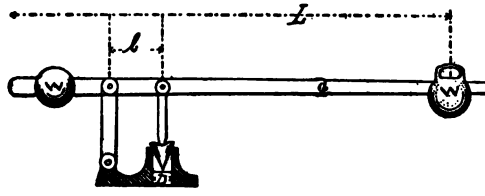


Fig. 13.

$$\text{Pressure } p = \frac{W\,L}{A\,l} \quad \ldots\ldots 12$$

Rule.—Multiply the weight W by the length of the long lever L, and divide this product by the product of the area A, multiplied by the short lever l; the quotient will be the pressure p per square inch.

$$\text{Lever } L = \frac{A\,p\,l}{W} \quad \ldots\ldots 13$$

Rule.—Multiply the area A of the valve v by the pressure p, in pounds per square inch, and this product by the length of the short lever l, and divide this last result by the weight W in pounds; the quotient will be the length of the long lever L.

Example 9.—A safety valve of the following dimensions, to find the weight W in pounds?

L=length of long lever in inches..... 40
l=length of short lever in inches..... 4
A=area of valve in square inches..... 5
p=the steam pressure in pounds per square inch.....100

Then by formula 11: $W=\frac{A\,p\,l}{L}$

Weight $W=\frac{5\times100\times4}{40}=50$ pounds.

Example 10.—A safety valve of the following dimensions, at what pressure p per square inch will it blow off?

W=the weight in pounds..... 10
L=the long lever in inches..... 24
l=the short lever in inches..... 2
A=the area of the valve v in square inches. 3

Formula 12: $p=\frac{W\,L}{A\,l}$

Pressure $p=\frac{10\times24}{2\times3}=40$ pounds per square inch.

Example 11.—A safety valve of the following dimensions, how long must the long lever L be to blow off at 80 pounds?

A=the area of the valve v in square inches... 4
W=the weight in pounds.....80
l=the short lever in inches..... 3
p=steam pressure in pounds per square inch 80

Formula 13: $L=\frac{A\,p\,l}{W.}$

Long lever $L=\frac{80\times4\times3}{80}=32$ inches.

Lever safety valves, as generally made, are easily altered, and thus prevented from operating correctly.

The lever arm a of a safety valve should always be of a length suitable for the maximum pressure the boiler is to carry; or the weight secured to the lever arm a at the proper working distance, and to prevent overloading only *one weight* should be allowed on the lever arm a, and this placed at the end of the same.

EFFECTIVE AREA OF SAFETY VALVES.

The *effective area* is the opening for the flow of steam, due to the hight of lift of the valve. It is an annular opening, the area of which may be found by the following rules:

Valve-Sit Notations.

$\mathcal{E}$ represents the effective area of the annular opening through which the steam escapes.

h represents vertical hight in inches equal to the lift of the valve.

D represents the inner diameter of the valve sit in inches.

d represents the depth of the valve sit in inches.

v represents the angle of the valve sit to the plane of the valve.

π represents the circumference of a circle whose diameter D=1, and stands for 3.14159265.

Cos represents the cosine or the sine of the complement of the angle of the valve sit.

Sine represents the sine of the angle of inclination.

Tan represents the tangent of the angle or bevel of the valve sit.

For safety valves with flat sit, Fig. 14 gives an opening, when lifted, equal to the surface of a cylinder having the same diameter D, as that of the valve, and a hight equal to the lift h.

The effective area $\mathcal{E}$ of the annular opening, when there is no bevel to the valve, will be

$$\mathcal{E}=h\,\pi \qquad \ldots\ldots 14$$

Rule.—The effective area equals the vertical lift h, multiplied by the circumference π, when there is no angle; or,

$$Æ = D\ h\ 3.1416 \ldots\ldots\ldots\ldots\ldots\ldots\ldots 15$$

Rule.—The effective area equals the diameter D, multiplied by 3.1416, and this product by the vertical lift *h*.

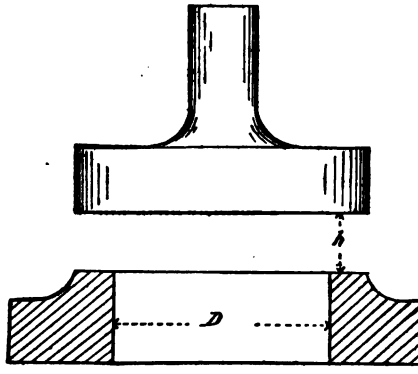


Fig. 14.

Lift of valve one-quarter of the diameter. Flat sit.

Example 18.—A flat valve sit (Fig. 14) without bevel, with D=2 inches, and lift $h = {}^1/_{16}$ or 0.0625

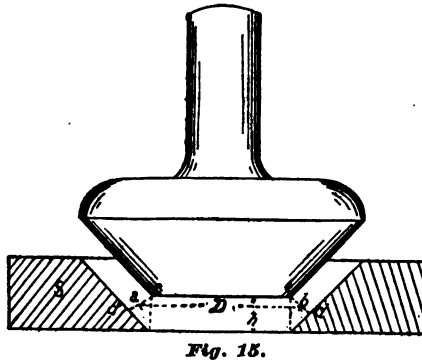


Fig. 15.

Lift of valve, half the depth of sit. Angle of sit, 45 degrees.

of an inch. What is the effective area Æ of the opening?

Formula 14: $Æ = h\ \pi$

Effective area $Æ = 0.0625 \times 6.283 = 0.3927$ sq. inches.

Formula 15: $Æ = D\ h\ 3.1416$.

Effective area $Æ = 2 \times 3.1416 \times 0.0625 = 0.3927$ sq. ins.

In the case of a valve sit with an angle or bevel v, Fig. 15, it is clear that the effective area $Æ$ of the annular steam passage will be equal to the surface of a frustum of a cone, and is the perpendicular distance $d\ e$, multiplied by the mean circumference of the diameter $a\ b$.

The distance $a\ b = D + \frac{1}{2}\ h$, which, multiplied by π, gives the circumference; or, $\pi\ (D + \frac{1}{2}\ h)$, when the angle v is 45 degrees.

Rule.—Multiply 3.1416 by the sum of the diame-

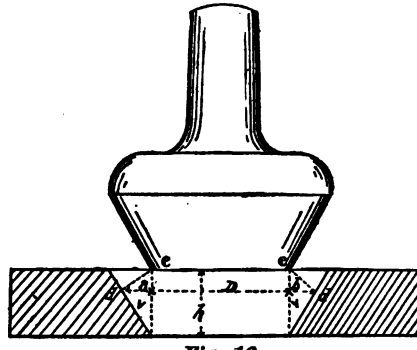


Fig. 16.

Lift of valve, the depth of sit. Angle of valve sit, 60 *degrees.*

ter D, added to one-half the vertical hight h, when the angle, or bevel v, is 45 degrees.

For any other angle use formula 16.

The distance $d\ e = h$ cosine v. That is to say, that the distance $d\ e$ equals the vertical hight h, multiplied by the cosine of angle v.

$$Æ = \pi\ h \cos v\ (D + \tfrac{1}{2}\ h \text{ sine } 2\ v) \ldots\ldots\ldots 16$$

Rule.—First, to the diameter D of the valve, add

one-half the vertical lift h, and multiply this sum by the sine of twice the angle v; second, multiply the circumference π of the valve by the vertical lift h, and by the cosine of the angle v; third, multiply the first product by that of the second, and the result will be the effective area Æ of the annular opening in square inches.

Example 14.—A safety valve having a diameter D=2 inches, and the valve sit has an angle v=25 degrees. What will be the effective area of the annular opening for a vertical lift h=¼, or 0.25, of an inch?

Formula 16: $Æ=\pi\ h \cos v\ (D+\frac{1}{2}h \sin 2\ v)$

Effective area $Æ=3.1416\times0.25\times0.906\ (2+\frac{0.25}{2}\times0.766)=1.157$ square inches; or,

First, $2\times\frac{0.25}{2}\times0.766 \quad =1.627.$

Second, $3.1416\times0.25\times0.906=0.7115$

Third, $1.627\times0.7115 \quad =1.157$ sq. inches.

Care must be taken in not confusing 2 v, or double the angle v, with 2 sine or double sines.

It will be seen in the above example that the angle v=25 degrees, 25×2=50 degrees, and the sine of which equals 0 766 (see table, page 40). The following is a simple formula for a valve sit of an angle of 45 degrees, and lift h, less than depth of sit.

$Æ=2.22\ h\ (D+\frac{1}{2}\ h)$.....17

Rule.—Multiply the number 2.22 by the lift h, and by one-half the lift h added to the diameter D, the product will be the effective area Æ, in square inches.

Example 15.—What will be the effective area Æ of the annular opening of a valve having a diameter D=2½ inches, for a lift h=¼ or 0.5 of an inch, the angle v of valve sit being 45 degrees?

Formula 17: $Æ=2.22\ h\ (D+\frac{1}{2}\ h)$

$$A = 2.22 \times 0.5 \left\{ 2.5 + \frac{0.5}{2} \right\} = 3.05 \text{ square inches.}$$

or, number	2.22
multiplied by vertical hight h	0.5
and this product multiplied by	1.110
the diameter D=2.5, plus $\frac{0.5}{2}$ =	2.75
Total square inches	3.0525

The following simple formula will also answer for angles of 30 degrees, with a lift less than the depth of the sit:

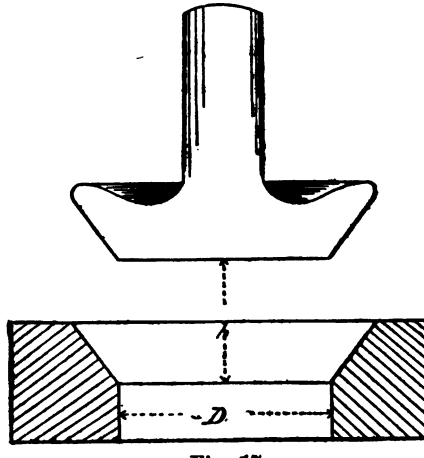


Fig. 17.

Lift of valve exceeding depth of sit. Angle of valve sit, 45 degrees.

$$A = 1.57\ D\ h + 0.68\ h^2 \quad \ldots\ldots 18$$

Rule.—First, multiply the diameter of the valve D by the vertical lift h, and by the number 1.57; second, multiply the square of the vertical lift h by the number 0.68, and add the two products together.

Example 16.—What will be the effective area of a safety-valve diameter D=2 inches, having an angle

v=30 degrees, and the vertical lift h=$\frac{1}{4}$ or 0.0125 of an inch? What will be the effective area of the annular opening for a lift h=$\frac{1}{16}$, or 0 0625 of an inch?

Formula 18: $Æ = 1.57\ D\ h + 0.68\ h^2$

Effective area $Æ = 1.57 \times 2 \times 0.0625 + 0.68 \times 0.0625 \times 0.0625 = 0.199$ square inches;

or $1.57 \times 2 \times 0.0625 =$.....	0.196250
and $0.0625 \times 0.0625 \times 0.68 =$.....	0.003656
Effective area in square inches...	0.199912

The Special Committee of the Board of Supervising Inspectors of Steam Vessels of the United States on safety-valve tests at the Washington navy yard, in September, 1875, made use of the following formula. All the safety valves on trial had valve sits at an angle of 45 degrees:

$$Æ = D + \tfrac{1}{2}\ h\ 3.1416\ h \times 0.71 \quad \ldots\ldots 19$$

Rule.—First, to the diameter D of the valve add one-half the vertical lift h; second, multiply this sum by 3.1416, and this multiplied by the product of lift h, multiplied by the number 0.71, gives the effective area.

Example 17.—A safety valve has a valve diameter D=2 inches, and a lift h $\frac{1}{4}$ or 0.5 inch, the angle v=45 degrees, what will be the effective area of the annular opening?

Formula 19: $Æ = D + \tfrac{1}{2}\ h\ 3.1416\ h \times 0.71$

Effective area $Æ = 2 \dfrac{0.5}{2} \times 3.1416 \times 0.5 \times 0.71 = 2.5$ square inches.

In case the lift h of the valve exceeds the depth of its sit, the area of excess of lift h is obtained as follows: Multiply the diameter D by the additional lift h, and by the circumference π—3.1416; this will be the area opening due to lift h above the valve sit, in square inches. Add this area to that due to the depth of the valve sit, and it will give the total effective area $Æ$, in square inches.

Example 18.—The diameter of a safety valve D—4 inches, and the angle v—45 degrees, and the depth of sit $\frac{1}{8}$ or 0.125 inches, what is the area of the annular opening for a lift of $\frac{1}{4}$ or 0.25 of an inch?

First, calculate the area of opening for a valve v— 45 degrees, for a lift h—$\frac{1}{8}$ or 0.125.

Formula 17: $Æ = 2.22\ h\ (D + \frac{1}{2}\ h)$

Effective area $Æ = 2.22 \times 0.125 \left\{ 4 + \frac{0.125}{2} \right\} = 1.124$ square inches.

Second, calculate the amount of opening due to the lift h above the sit, which, in this example, is $h\ \frac{1}{8}$ or 0.125 of an inch.

Formula 20: $Æ = D\ h\ 3.1416$

Effective area $Æ = 4 \times 0.125 \times 3.1416 = 1.570$

Third, add these values together:

Effective area due to lift above valve sit.....1.570
Effective area due to lift to top of valve sit....1.124

Total effective area in sq. ins. due to $\frac{1}{4}$ in. lift—2.694

THE VALUE OF THE SINES, COSINES AND TANGENT ANGLES, FROM 20 TO 60 DEGREES.

Angle.	Sine.	Cosine.	Tangent.	Angle.	Sine.	Cosine.	Tangent.
20°	.342	.940	.364	41°	.656	755	.869
21°	.358	.934	.384	42°	.669	.743	.900
22°	.375	.927	.404	43°	.682	.731	.933
23°	.391	.921	.424	44°	.693	.719	.966
24°	.407	.914	.445	45°	.707	.707	1.000
25°	.423	.906	.466	46°	.719	.695	1.036
26°	.438	.899	.488	47°	.731	.682	1.072
27°	.454	.891	.510	48°	.743	.669	1.111
28°	.469	.883	.532	49°	.755	.656	1.150
29°	.485	.875	.554	50°	.766	.643	1.192
30°	.500	.866	.577	51°	.777	.629	1.234
31°	.515	.857	.601	52°	.788	.615	1.279
32°	.530	.848	.625	53°	.798	.607	1.327
33°	.545	.839	.649	54°	.809	.588	1.376
34°	.559	.829	.675	55°	.819	.573	1.428
35°	.574	.819	.700	56°	.829	.550	1.482
36°	.588	.809	.727	57°	.838	.544	1.540
37°	.602	.799	.754	58°	.848	.530	1.600
38°	.616	.788	.781	59°	.857	.515	1.664
39°	.629	.777	.810	60°	.866	.500	1.732
40°	.634	.766	.839				

DIAMETER OF SAFETY VALVES.

The effective area Æ of the valve being known, and the hight or lift h, the diameter can be calculated as follows: For a valve sit without bevel

$$D = \frac{Æ}{h\ 3.1416} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 20$$

Rule.—Multiply the lift h of the valve by the number 3.1416, and divide the area of opening by this product.

Example 19.—A safety valve having an effective area Æ—0.3927 when the valve lifts $h = {}^1/_{16}$ or 0.0625 of an inch. What should be its diameter?

By formula 20:

$$\text{Diameter } D = \frac{0.3927}{0.0625 \times 3.1416} = 2 \text{ inches.}$$

or,

Number.....	3.1416
Multiplied by lift.....	0.0625
	0.19635

$$\frac{0.3927}{0.19635} = 2 \text{ inches.}$$

Having given, the effective area Æ, formula 16, and the hight h lifted, the diameter D is found from the above formula as follows:

$$\frac{Æ}{\pi\ h \cos.\ v} = D + \tfrac{1}{2}\ h \sin.\ 2v;$$ of which the

$$\text{diameter } D = \frac{Æ}{\pi\ h \cos.\ v} - \tfrac{1}{2}\ h \sin.\ 2v \quad \ldots\ldots 21$$

Having given the inside diameter D, and the required effective area Æ, the lift or hight h to which the valve must be lifted, is as follows:

$$h^1\ \pi\ D \cos.\ v = Æ - \tfrac{1}{2}\ h \sin.\ 2v\ \pi\ h \cos.\ v$$

$$h\ \pi\ D \cos.\ v = Æ - h^2\ \tfrac{1}{2} \sin.\ 2v\ \pi\ h \cos.\ v$$

$$h^2\ \tfrac{1}{2} \sin.\ 2v\ \pi \cos.\ v + h\ \pi\ D \cos.\ v = Æ$$

$$h^2 + h\left\{\frac{2\,\pi\,D\cos.\,v}{\sin.\,2v\,\pi\cos.\,v}\right\} = \frac{Æ}{\sin.\,2v\,\pi\cos.\,v}$$

Half the square of the coëfficient for h is

$$\left\{\frac{D}{\sin.\,2v}\right\}^2$$

Add this on both sides of the = signs.

$$h^2 + h\left\{\frac{2D}{\sin.\,2v}\right\} + \left\{\frac{D}{\sin.\,2v}\right\}^2 = \frac{2Æ}{\sin.\,2v\,\pi\cos.\,v} + \left\{\frac{D}{\sin.\,2v}\right\}^2$$

The square root of this formula will be

$$h + \frac{D}{\sin.\,2v} = \sqrt{\frac{2Æ}{\sin.\,2v\,\pi\cos.\,v} + \left\{\frac{D}{\sin.\,2v}\right\}^2}$$

Then

$$\text{Hight } h = \sqrt{\frac{2Æ}{\sin.\,2v\,\pi\cos.\,v} + \left\{\frac{D}{\sin.\,2v}\right\}^2} - \frac{D}{\sin.\,2v} \quad \ldots\ldots\ldots 22$$

Example 20.—A safety valve has a diameter D=2 inches, and the valve sit has a bevel or angle v=25 degrees. What is the effective area Æ, if the annular opening for a lift h=¼ or 0.25 of an inch?

Formula 16: $Æ = \pi\,h\cos.\,v\,(D + \frac{1}{2}\,h\sin.\,2\,v)$

$$\text{Effective area } Æ = 3.1416 \times 0.25 \times 0.906\left\{2 + \frac{0.25}{2}\right\} \times$$

$\times 0.766 = 1.493$ square inches.

The diameter D, in example 18, can be found by using the other dimension by

$$\text{Formula 21: } D = \frac{Æ}{\pi\,h\cos.\,v} - \frac{1}{2}\,h\sin.\,2\,v$$

$$\text{Diameter } D = \frac{1.493}{3.1416 \times 0.25 \times 0.906} = 2.15 - \frac{0.25}{2} \times$$

$\times 0.766 \times 909 = 2.054$ inches.

And the lift h as follows.

Formula 22:

$$h = \sqrt{\frac{2\,Æ}{\sin.\ 2\,v\ \pi\ \cos.\ v} + \left\{\frac{D}{\sin.\ 2v}\right\}^2} + \frac{D}{\sin.\ 2\,v}$$

$$\text{Lift } h = \sqrt{\frac{2.986}{0.766 \times 3.1416 \times 0.906} + \left\{\frac{2}{0.766}\right\}^2} - \frac{2}{0.766} = 0.2503$$

or as follows:

The sine of $2\,v = 25° \times 2 = 50° =$.....	0.766
Multiplied by $\pi =$.....	3.1416
	2.4064656
Multiplied by cosine $v = 25° =$.....	0.906
First product.....	2.1802578336
Divide $2\,Æ = 1.493 \times 2 =$ 2.986 ——— =	1.36956
By the first product....2.1802578336	
Then divide diameter D= 2 ——— =	2.611
By the sine $2\,v = 25° \times 2° = 50° =$ 0.766	
Square this quotient $2.611 \times 2.611 =$	6.8173
To this add the first quotient	1.36956
	8.18676

The square root of this sum $\sqrt{8.18676} = 2.8613$

Now divide diameter D=2 ——— =2.611

By the sine $2\,v = 25° \times 2 = 50° = 0.766$

Subtract this latter quotient from the root of the above, and the remainder will be the lift $h =$ ..... 0.2503 inches.

TO FIND THE ANGLE OF A VALVE SIT.

From the largest diameter subtract the smallest diameter, and divide half this difference by the depth of bevel of the valve sit, and the quotient is the tangent of the angle v.

The algebraic expression is as follows:

Let D=largest diameter of valve sit in inches.

d=smallest diameter of valve sit in inches.

k=depth of valve sit in inches.

v=angle, or bevel.

$$\text{Tangent } v = \frac{D-d}{2k} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 23$$

Example 16.—The largest and smallest diameters of a valve sit are D=3½ and d=2½ inches respectively, and the depth k=¼ or 0.5 inch. What will be the angle of the valve sit?

Formula 23: Tangent $v = \frac{3.5-2.5}{0.5\times 2} = 1$, the tangent of the angle of the valve sit.

Or, largest diameter D=3.5
Smallest diameter d=2.5

1.0

$0.5\times 2 = 1.0$

Tangent v=1

The angle corresponding to this tangent by table is 45 degrees.

SAFETY VALVE AREAS.

The writer, in 1867, had the honor of being appointed by the president, one of a committee of four members of the Franklin Institute, to which was referred the consideration of the legal requirements which should be made for safety valves and pressure gauges upon steam boilers erected in the city of Philadelphia, in accordance with acts of the Assembly of the State of Pennsylvania, approved May 7, 1864. The following report was approved by ordinance of councils of the city of Philadelphia, July 13, 1868:

The committee did not in American or English practice of engineers or boiler-makers find any general rule of dimensions of safety valves, that had been acknowledged, relating to other dimensions of boilers, or to the pressure of steam or the rates of combustion of fuel, although such relationship is admitted by the assumption and practice of different constructors without any definite rule.

Neither have those writers in our language, whose works are regarded as authoritative upon the subject

of steam and the steam engine, nor has American or English legislation, established or stated suitable proportions and requirements for the various conditions. On the other hand, the laws of France, Prussia, and other continental nations, have been framed with an evident appreciation of the essential demands, and established areas of valve openings for all sizes of, and pressures of steam in, boilers, so that it had only remained for the committee to translate into English measures, to modify the ratios by using, as the surface of comparison with the safety valve area, the grate surface in place of that adopted by the French—boiler surface, and to make a further correction by embracing in the rule the differing rates of combustion upon the grate surface.

The committee have not found, nor have they sought very carefully, the reasoning upon which the French rule, or formula, has been based, and will say that they reached the same conclusion independently, and were not a little surprised by the coincidence after their own investigation.

We proceed to give, as briefly as possible, those considerations which control or influence this question of area of safety valves:

A safety valve is a loaded valve covering an orifice opening outwards from a boiler, which valve is intended to lift whenever the pressure of steam within the boiler rises above that to which the valve has been loaded; and the opening thus produced ought to discharge the steam of the boiler in such quantities that the pressure within shall not exceed, to any considerable degree, or beyond some fixed limit, the defined pressure at which the valve opened.

Upon this proposition, it is evident that a safety valve may sometimes be required to discharge all the steam which, under the most favorable conditions, may be formed by evaporation in any given time. As the rapidity of the evaporation of water is evidently the result of rapidity of combustion of fuel, which itself refers to extent of grate surface and strength of draught or blast (supply of air), we take the grate surface, or area, as that element of a

steam boiler presenting the most readily-measured surface for comparison with the required area of the opening or least section of the aperture or channel of discharge of an opened safety valve. We can assume that the draught or supply of air to the fuel being burned under any given steam boiler, is, on the average, that existing in ordinary stationary steam boilers with chimney draught, and afterwards correct our proportions for forced draught or blast, and more active combustion. In like manner, we can modify the results, based on this assumption, to suit the conditions of boilers which are heated by the waste heat or by the burning of gases unconsumed in manufacturing processes. As it is the object of investigation to determine that area of safety valve needed to insure safety, it is proper to give so great an excess above the absolute demand for the sectional area of the vein of steam escaping from a boiler under any given pressure as will be sure to cover the emergency of extraordinary rapidity of combustion during any short period of time, and also to include the coëfficient of resistance to discharge through a passage offering as much resistance as the one formed by lifting a disk valve of the ordinary construction from a flat seat.

We here notice that there may be so large an excess of area that the opening of the valve may, by its sudden relief of pressure and discharge of steam, especially in boilers with limited water surface for the elimination of the steam from the water, dangerously disturb the equilibrium of circulation of water within the boiler; and also that the safety valve may be so badly formed, in regard to shape of disk and seat, that after lifting a little without any change of load upon the valve, the pressure within the boiler may dangerously increase, while a small quantity of steam only is discharged. In both of these points of difficulty we will refer to the practice of engineers, only saying here that the ratio of excess which we assume, when applied to the case of the gradual rising of temperature and pressure which occurs in a boiler containing a mass of water, and only ad-

mitting the gradual opening of the valve, is much below any dangerous condition, and our assumed excess is really additional safety. The assumption of considerable excess also allows us, when in our theoretical examination we find considerations of obviously very small value, to reach, in a practical form, a perfectly satisfactory general result. Proceeding on these grounds, therefore, let us take the average combustion of a well-set or arranged boiler at 8 pounds of coal (or fuel equivalent) per square foot of grate per hour, and that the maximum combustion, when the fire is in the best condition, and is evolving heat most rapidly, can be taken at three times that of the average. That is, for a portion of time we must assume that the rate of burning will be 24 pounds of coal per square foot of grate per hour. We can estimate with the slow rate of average combustion assumed, and with adequate heating surface to the boiler, which surface shall be in good working order, both within and without, that there will be evaporated 9 pounds of water to each pound of coal consumed. This gives a maximum rate of evaporation of 216 pounds of water per square foot of grate per hour, or 0.06 pound of water per square foot of grate per second.

On the grounds stated in a preceding paragraph, we may neglect the increase of heat demanded for the evaporation of water at higher temperatures than 212 degrees, and assume, within our limits of 20 to 120 pounds above the atmosphere, the weight of water evaporated or quantity of steam produced by the combustion of a given quantity of fuel to be constant.

Whatever error there is, from taking a larger quantity of steam at the higher pressures than is actually produced in the result, only adds to the dimensions of the safety valve of such higher pressures, and is an error in a safe direction, as well as a very small one.

When we come to the discussion of how great an allowance of excess of size over absolute requirement is to be made, we take first the coëfficient of friction, as found by experiment on the flow of liquids through apertures and passages of a character simi-

lar to the passage of a safety valve: $Æ=1.5\ a$ where $Æ$ is the area of absolute requirement sought, and a the sectional area of the vein or tube of fluid, supposing no resistance from the mouth of discharge to exist. And secondly, the practical coëfficient employed to give adequate excess of area of valve for all contingencies. This last has been taken at eight times the area of absolute requirement; or $A=8\ Æ=12\ a$, where A is the area of the valve sought, and a, as before, the values of $Æ$, A and a, being taken in square inches.

The most simple equation expressing the relation of volumes of steam to water, applicable to our purpose, is that given as the result of experiment by Fairbairn and Tate:

$$W\ p=\frac{389}{p+15.052}+0.41$$

Where $W\ p$=the volume of one pound of steam in cubic feet, under any nominal pressure p per square inch above the atmosphere. Whence we have:

$$W=0.06\left\{\frac{389}{p+15.052}+0.41\right\}=\text{cubic feet of steam}$$

formed, under our supposition, per second.

The hight of column to effect the discharge of steam under any pressure p (per square inch), is evidently equal to the volume of p pounds of steam multiplied by 144.

$$h=144p\left\{\frac{389}{p+15.052}+0.41\right\}$$

and the theoretical velocity of discharge in feet per second $=v=8.025\ \sqrt{h}$.

$$\therefore v=8.025\ \sqrt{144p\left\{\frac{389}{p+15.052}+0.41\right\}}$$

The size of the vein a (in square feet), which will convey the volume W at the velocity v per second, is:

$$a^1=\frac{W}{v}=\frac{0.06}{12\times 8.025}\,\frac{\frac{389}{p+15\,052}+0.41}{\sqrt{p\,\frac{389}{p+15.052}+0.41}}$$

but $144\,a^1=a$, and $12\,a=A$. $\therefore A=1728\,a^1$

$$\therefore A=\frac{1728}{12}\times\frac{0.06}{8.025}\sqrt{\frac{\left\{\frac{389}{p+15.052}+0.41\right\}^2}{p\left\{\frac{389}{p+15.052}+0.41\right\}}}$$

Taking the above facts into consideration, the committee arrived at the following formula:

$$A=21.23\sqrt{\frac{1}{A}\left\{\frac{1}{p+15.052}+0.00195\right\}}\quad\ldots\ldots\ldots 24$$

We will now compare this with the legal formula of France, which reads:

$$A\text{ (in centimeters)}=0.00053\,\frac{s\text{ (in meters)}}{n-0.412}$$

where

A=area of safety valve.

s=heating surface of boiler in square meters.

n=absolute pressure of steam in atmospheres.

We can safely take the French practice in construction of their boilers at 20 units of boiler surface to each unit of grate surface, as the boilers in general use in France assimilate in these ratios to those of our long cylinder or two-flued forms, when the proportions generally correspond. Substituting this value, and taking 14.7 pounds for the atmospheric pressure, deducting one atmosphere of constant pressure, and reducing the whole to American weights and measures, we have:

$$A=\frac{22.5\,G}{p+8.62}\quad\ldots\ldots\ldots 25$$

where

A=area in square inches of safety valve per square foot of grate surface.

The results of the two formulas are given below:

Formula 24, as calculated: $A=21.23\ p\left\{\frac{1}{p+15.052}+0.0195\right\}$

Pressure in pounds per square inch.	10	20	30	40	50	60	70	80	100	120
Area of safety valve per square foot of grate (sq. inches).	1.33	0.815	0.589	0.465	0.384	0.328	0.287	0.257	0.209	0.178

Formula 25, as given in French law: $A=\frac{22.5\ G}{p+8.62}$

Pressure in pounds per square inch.	10	20	30	40	50	60	70	80	100	120
Area of safety valve per square foot of grate (sq. inches).	1.21	0.736	0.538	0.461	0.394	0.346	0.306	0.274	0.227	0.195

This coincidence of results could only have existed from having the same basis, and the difference of form of the two second terms can only have arisen from the using of some other and more tractable empirical formula for the volume of steam by those who originated the French rule.

The divergence below 20 pounds we do not consider essential, whether the calculated formula gives too large values or the French one gives too small, and we would recommend for adoption the more simple formula:

$$A = \frac{22.5\ G}{p + 8.63} \quad \ldots\ldots\ldots\

combustion depends, in a great measure, upon the intensity of the fire, and a maximum rate of 24 pounds may, and probably does, accompany an average rate of 8 pounds of coal per square foot of grate per hour; while with artificial draught, or blast, this rapidity of combustion is nearly independent of the condition of the fuel, and a maximum rate of 24 pounds will hardly be exceeded with an average one of 16 pounds. We think it safe to take this quantity of 16 pounds average combustion per hour, with or by the aid of induced or produced supply of air to the fuel (as with jets or by fans), as an equivalent to the one square foot of grate surface which we had taken as the unit of comparison with the area of the safety valve. That is, the area of one square foot of grate, *without* artificially accelerated draught, may be assumed to require the same area of safety valve, as the burning of 16 pounds of coal per hour, *with* such draught, properly demands.

As regards those boilers which are heated by the waste heat of furnaces, or by the combustion of waste gases from some processes of manufacture, the circumstances are too variable to admit of statement in any law, and only the judgment of competent mechanics upon the performance of such boilers or steam generators, can determine the proper area of safety valves for them.

If the area given by the formula be applied to the opening of the seat of the safety valve, it is obvious that the vertical lift of the valve must be at least one-fourth the diameter, to have the same sectional area when open.

Hence, should any valve be so constructed that the range of motion will not admit, when fully raised, a lift equal to one-fourth the diameter of the opening of the seat of the valve, the sectional area actually given between the raised valve and the edge of the valve seat should be taken as that to which the rule applies.

And while the formula gives areas abundantly large to meet the general resistance to discharge, which proceeds from the necessary form of a disk

resting upon, or placed in proximity to, a seat, we think we ought here to state that it is always advisable that the under sides of safety-valve disks should have a globular or pointed form (whether with or without guide-wings), and not made flat, as they sometimes are, and that the disks be beveled-edged, resting upon a very narrow beveled seat, and do not have a flat bearing. It may be well to state, also, that, as ordinarily constructed, a safety valve, after lifting and allowing a flow of steam all around the disk, does not continue to raise and allow all the steam, as formed, to escape at the constant pressure, but admits some elevation of pressure before opening wide. With the areas given by the formula, and where the disks have been shaped as we have before described, this increase of pressure will not exceed 10 per cent of the initial load on the valve, and the additional resistance to opening is a safeguard against the too sudden relief of steam, to the derangement of the water circulation of the boiler.

The committee will only add, as regards further consideration of the form or description of safety valves, and as to legal requirements beyond the adequacy of the openings, that the subject becomes too extensive for them to consider.

As originally made in the days of Watt—almost as planned by Papin—the essential parts of the safety valve have substantially remained until this time. No patent covers its simplicity or improves its certainty, although there have been made and used a thousand kinds, and there are a hundred existing patents.

It can only be imperfect by palpable misconstruction, or unsafe by vicious intent, and we can only recommend the defects to competent inspection, with power to remedy, and the misuse to the punishment of the law. There is very little likelihood that a safety valve, properly constructed, and in proper hands, would get out of order or fail to act at the needed moment. But, on the supposition that such a catastrophe might occur, it has been thought by the committee, after much deliberation, that, in order to divide the small chance for failure,

it may be as well to make it a legal requirement, that in place of one safety valve, each and every boiler shall have at least two, the aggregate area of which should be that established by the formula.

These valves ought to be loaded with the same load, and blow off indiscriminately, so that either or both may be in action at once. This plan would call for, and insure, more care in graduating the loads on safety valves than is at present employed. The committee feel justified in observing that there are now in use more safety valves improperly graduated or marked, than there are those imperfectly or unsuitably constructed. Lock-up safety valves afford but little protection from fraud or over-pressure, and less security, unless frequently tested; and their use is decidedly discountenanced by the committee. We conclude our discussion of this branch of the subject committed to us, by recommending for the approval of the Institute the following

SCHEDULE,

giving the least aggregate area of safety valves (being the least sectional area for the discharge of steam) to be placed upon all stationary boilers with natural or chimney draft. This area may be expressed by the formula:

$$A = \frac{22.5\ G}{p + 8.62}$$

in which

A=area of combined safety valve in square inches.

G=surface of grate in square feet.

p=pressure of steam in pounds per square inch to be carried in the boiler above the atmosphere, as shown by the steam gauge.

The following table gives the results of the formula for one square foot of grate, as applied to boilers used at different pressures:

Pressure in lbs. per sq. inch.	10	20	30	40	50	60	70	80	90	100	120
Area in sq. ins. corresponding to each square foot of grate.	1.21	0.79	0.58	0.46	0.38	0.33	0.29	0.25	0.23	0.21	0.17

We give one example of the application of the figures given by the table:

Suppose the boiler to be worked under 60 pounds pressure, then each square foot of grate surface should have an area of safety valve, by the table, of } =0.33 square inch.

Suppose the boiler to have 18½ square feet of grate surface } =18.5

18.5×0.33=6.105 square inches area for the safety valves.

This would call for two safety valves, each having an area of 3.05 square inches, or a diameter of 2 inches.

Where boilers have a forced or artificial draft, the combustion of 16 pounds of coal per hour should be taken as equivalent to the one square foot of grate surface=G in the above formula and table.

Where boilers are heated by the waste heat of furnaces, or otherwise than by fire upon grates, the value to be taken for G must be estimated by some competent person, based upon the comparative performance of boilers with others heated in the usual way.

And the committee would report on the second branch of the subject referred to them—the legal requirements which ought to be made as to pressure gauges—that the time allotted to them has not permitted a complete investigation. The great advantage which any of these instruments possess, is found in their indicating the pressure of steam within a boiler, so as to allow a fireman to regulate his supply of fuel with economy. There are many kinds and forms of gauges, almost every one of which has some characteristic superiority over all, or most other kinds and forms, but we do not wish to say that any of them are perfectly or permanently reliable.

And your committee would ask to be relieved from further consideration of the subjects referred to them.

ROBERT BRIGGS,
COLEMAN SELLERS,
J. VAUGHAN MERRICK,
WM. BARNET LE VAN.

SAFETY VALVE AREAS.

The following formulas are in use in different countries, and give the areas of the safety-valve chamber or pipes closed by the valves (not the *annular orifice* due to the lift of the valve from its seat, or its effective area as represented by the notation Æ).

Notation of Letters.

A=area in square inches of the smallest diameter of the valve sit.

Æ=area through which the steam escapes, which is equal to the circumference of the smallest diameter of the valve sit, multiplied by the lift h of the valve—$h\ \pi$=Æ, or (3.1416 h).

P=total or absolute steam pressure in pounds per square inch p+15.

p=steam pressure above that of atmosphere, or that shown by the steam gauge.

¶=weight in a fraction of a pound per cubic foot of the steam pressure p (see page 400, Steam Tables, "Nystrom's Pocket-Book.")

V=steam volume compared with that of its water at 32° Fah.

H=hight in feet of a column of steam of one square foot section, which weight would be equal to the steam pressure per square foot, or 144 p.

V=velocity in feet per second of the steam through the safety valve.

G=area of the fire grate in square feet.

□=area of the heating surface in square feet.

lbs.=pounds of water evaporated per hour.

c=coal burned per hour in pounds.

Franklin Institute Formula.

$$A=\frac{G\ 22.5}{p+8.62}\quad\text{.....27}$$

Rule.—1st. Multiply the area of the fire grate by the constant number 22.5.

2d. Add the constant number 8.62 to the steam pressure in square inches.

3d. Divide the first quantity by the second. The

quotient will be the area of the valve sit. The Franklin Institute recommends two safety valves for each boiler, therefore one-half of the above area will be the proper area of each safety valve, at its smallest diameter for each safety valve.

The French rule is the same as that of the Franklin Institute, except one or more safety valves may be used.

Prussian Formula.

$$A = \frac{1.2}{P+15} \square \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 28$$

Rule.—1st. Add 15 to the steam pressure per square inch.

2d. Divide 1.2 by the first quantity, and multiply the quotient by the square feet of heating surface $\square$; the product will be the area of smallest diameter in square inches.

J. W. Nystrom's Formula.

$$A = \frac{\mathbf{V} \sqrt{G} \square}{288} \sqrt{\frac{\P}{p}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 29$$

Rule.—1st. Multiply the steam volume $\mathbf{V}$, compared with that of its water at 32° Fah., and by the square root of the area of heating surface in square feet, multiplied by the area of the grate surface in square feet.

2d. Divide this product by the constant number 288.

3d. Multiply the above quotient by the square root of the quotient of the weight $\P$, in a fraction of a pound per cubic foot of the steam pressure p, divided by the steam pressure p, as shown by the steam gauge. The quotient will be the area of the smallest diameter of valve sit.

Institute of Engineers and Ship-Builders in Scotland Formula.

$$A = \frac{G\ 18}{P+15} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 30$$

$$\text{or } A=\frac{\square\ 0.6}{p+15}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 31$$

Rule.—Multiply the number 18 by the grate surface in square feet G, and divide this product by the steam pressure p, plus 15.

Or, If the heating surface in square feet ($\square$) exceed *thirty* square feet per square foot of grate surface, it is to be determined by the heating surface.

Rule.—Multiply the square feet of heating surface $\square$ by the number (0.6), and divide the product by the steam pressure (p) in pounds per square inch, plus 15. This sum will be the area in square inches of each of the valves, two safety valves being recommended.

United States Board of Supervising Inspectors of Steam Vessels Formula.

$$A=0.005 \text{ lbs}.\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

Rule.—Multiply the number of pounds of water evaporated per hour by 0.005; the product will be the area of the valve sit in square inches at its smallest diameter.

United States Formula.

$$A=\frac{\square}{25}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 33$$

Rule.—Divide the number of square feet ($\square$) of heating surface in the boiler by 25, and the quotient is the area in square inches of the valve sit at its smallest diameter.

English Formula.

$$A=\frac{G}{2}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 33$$

Rule.—For boilers with natural draft, divide the square feet of the fire grate by 2, and the quotient is the area in square inches for the smallest diameter of valve sit.

Molesworth's Formula.

$$A=G\ 0.8.\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 34$$

Rule.—Multiply the square feet of fire grate by the number 0.8, and the product will be the square for area of valve sit.

Professor Rankine's Formula.

A=lbs. 0.006.....85

Rule.—Multiply the pounds of water evaporated per hour by the number 0.006, and the product will be the area of valve sit.

Professor Thurston's Formula.

$$A=\frac{c\,4}{p+10}\text{.....}\text{.....}86$$

or $$A=\frac{\square\ 5}{2(p+10)}\text{.....}$$

Rule.—1st. multiply the pounds of coal (c) burned per hour by the number 4.

2d. Add the number 10 to the steam pressure (p); divide the first quantity by the second, and the quotient will be the area in square inches.

Or, in second formula:

1st. Multiply the heating surface ($\square$) by the number 5.

2d. Add the number 10 to the steam pressure (p), and multiply the sum by the number 2; divide the first quantity by the second.

It will be seen by the following examples that these rules and formulas give widely different results:

Example 22.—A steam boiler having 20 square feet (G) of fire grate, and 600 square feet ($\square$) of heating surface, carrying p=80 pounds of steam pressure per square inch above that of the atmosphere, consuming c=300 pounds of coal per hour, and evaporating lbs.=2,000 pounds of water per hour. Required, the area A of the safety valve?

First. Franklin Institute formula:

$$\text{Area A}=\frac{\text{G }22.5}{p+8.62}$$

$$\text{or, } \frac{20\times22.5}{80+8.62}=5 \text{ square inches.}$$

Second. Prussian formula:

$$\text{Area } A=\frac{1.2}{p+14}$$

$$\text{or, } \frac{1.2}{80+15}=7.57 \text{ square inches.}$$

Third. John W. Nystrom's formula:

$$\text{Area } A=\sqrt{\frac{G\square}{288}}\sqrt{\frac{\P}{p}}$$

$$\text{or, } \frac{280.5\sqrt{20\times600}}{288}\sqrt{\frac{0.22241}{80}}=5.625 \text{ square inches.}$$

Fourth. Institute of Engineers and Ship-Builders in Scotland formula:

$$\text{Area } A=\frac{G\ 18}{p+15}$$

$$\text{or, } \frac{20\times18}{80+15}=3.79\times2=7.58 \text{ square inches.}$$

$$\text{and } A=\frac{\square 0.6}{p+15}$$

$$\text{or, } \frac{600\times0.6}{80+15}=3.79\times2=7.58 \text{ square inches.}$$

The Institute of Engineers and Ship-Builders in Scotland recommend that two safety valves be fitted to each boiler—the same as recommended by the Franklin Institute of Philadelphia.

Fifth. United States Board of Supervising Inspectors of Steam Vessels formula:

$$\text{Area } A=0.005 \text{ lbs.}$$

or, $0.005 \times 2000 = 10$ square inches.

Sixth. United States formula:

$$\text{Area } A = \frac{\square}{25}$$

$$\text{or, } \frac{600}{25} = 24 \text{ square inches.}$$

Seventh. English formula:

$$\text{Area } A = \frac{G}{2}$$

$$\text{or, } \frac{20}{2} = 10 \text{ square inches.}$$

Eighth. Molesworth's formula:

$$\text{Area } A = G\ 0.8$$

or, $20 \times 0.8 = 16$ square inches.

Ninth. Professor Rankine's formula:

$$\text{Area } A = \text{lbs. } 0.006$$

or, $2000 \times 0.006 = 12$ square inches.

Tenth. Professor Thurston's formula:

$$\text{Area } A = \frac{c\,4}{p + 10}$$

$$\text{or, } \frac{300 \times 4}{80 + 10} = 13.3 \text{ square inches.}$$

$$\text{and } A = \frac{\square\,5}{2\,(p + 10}$$

$$\text{or, } \frac{600 \times 5}{2\,(80 + 10)} = 16.6 \text{ square inches.}$$

The following table shows the respective area of safety valve outlets from the boiler in question at

different steam pressures, according to the practice of the English Board of Trade, Institution of Engineers and Ship-Builders in Scotland, Prussian law, and the Franklin Institute formula, the latter being identical with that in use in France. The Scottish engineers recommend that two safety valves be fitted to each boiler. The formula gives the area for one of these valves, which, being doubled, gives the proper area for the boiler, their recommendation agreeing with that of the Franklin Institute that there shall be two or more safety valves for each boiler when fired separately.

Steam Pressure p as per Steam Gauge.	AREAS OF VALVES AS RECOMMENDED BY THE FOLLOWING COUNTRIES.			
	British.	Scottish.	Prussian.	America. Franklin Institute.
	$A=\frac{G}{2}$	$A=\frac{G\ 18}{p+15}\times 2$	$A=\frac{1.2}{p+15}\square$	$A=\frac{G\ 22.5}{p+8.62}$
5	10	36	36	33
10	10	28 8	28.8	23.11
15	10	24	24	19
20	10	20 4	20.4	15.7
25	10	18	18	13.38
30	10	16	15 6	11.6
35	10	14.4	14 4	10.3
40	10	13	13.6	9.25
45	10	12	12	8.4
50	10	11	10.8	7.6
55	10	10 28	10.2	7
60	10	9 6	9.6	6.5
65	10	9	9	6
70	10	8.46	8.4	5.7
75	10	8	7.8	5.3
80	10	7 58	7 5	5
85	10	7 2	7 2	4 8
90	10	6 84	6.84	4.5
95	10	6 54	6 54	4.34
100	10	6 26	6 24	4.14

It will hereafter be shown by the experiments of James Brownlee, of the Institution of Engineers and Ship-Builders, in Scotland, that the Franklin Institute formula, although giving the smallest area of valve, is, at all steam pressures above 25 pounds

per square inch, when full open (one-quarter the diameter of valve outlet), five times that requisite to discharge all the steam generated; the Scottish and Prussian rule, nine times; while by the British formula it is four and a half times at 25 pounds steam pressure, and eighteen times more than is required at 130 pounds pressure, and this, after allowing for an evaporation of 8 pounds of water per minute per square foot of fire grate, which is considerably more than is usually realized in practice.

So that with properly constructed safety valves, which will rise one-fourth of their diameter by an increase of 1 to 5 pounds above the load, there is no necessity for the area being much (if any) more than one-fifth of that called for by the Franklin Institute formula.

But as boilers are made of iron and steel—and as these materials, like man, wear out—the Franklin Institute formula gives ample margin for reduction of the steam pressure as the boiler deteriorates with age, so by the time the area becomes too small, the boiler will have to be renewed.

DIAMETER OF SAFETY VALVES.

When the area A is known, the diameter D of the valve sit can be found by the following formula:

$$\text{Diameter } D = \sqrt{\frac{A}{0.7854}} \quad \ldots\ldots\ldots\ldots\ldots\ldots 87$$

Rule.—Divide the area A of the valve by the number 0.7854, and extract the square root of the quotient.

AREA OF SAFETY VALVES.

When the diameter D is known, the area A of the valve sit can be found as follows:

$$A = 0.7854\ D^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 88$$

Rule.—Square the diameter in inches, and multiply this product by 0.7854.

In 1874, a most interesting series of experiments

on safety valves was made by a committee of the Institution of Engineers and Ship-Builders of Scotland. A discussion had arisen among the Scottish and English engineers relative to the proper construction of a safety valve, and the rules of the English Board of Trade as to the areas required and the mode of loading the valves.

In this trial two safety valves only were tested—those approved by the English Board of Trade—the united areas of which were one-half of a square inch area to each square foot of grate surface. The boiler used in this experiment was of the tubular kind, and the grate surface was 25 square feet; the heating surface, 746 square feet. The safety valves were each 2¾ inches diameter. The safety valves were loaded with weights direct.

The experiments were made by David Rowan, with steam pressures from 5 to 45 pounds. The object was to ascertain the increase of pressure in a boiler, when all the steam raised was allowed to pass away by the safety valves, unassisted at the different pressures. The following is the table of results:

Steam Pressure at which the Valve opened.	Steam Pressure rose to, in Pounds.	Percentage of Increase of Steam Pressure.	Lift of Valve in Inches.	Weight of Steam, in Pounds, Discharged.
5	13	160	0.325	3.39
10	19	90	0.255	3.223
15	25	66	0.18	2.68
20	30	50	0.16	2.676
25	36	44	0.1425	2.7
30	40	33	0.1262	2.58
35	44	25.7	0.1125	2.466
40	48¼	21	0.103	2.437
45	52	15.5	0.097	2.41

With flat-faced valves, according to the English Board of Trade rule, half of one square inch of area per foot of fire grate:

$$\text{The weight of steam } w = \frac{3\,P\,A}{2\,D}$$

But the valve sits being bevel to an angle of 45°

$$W = \frac{3\,P\,A}{2.8\,D}$$ Weight of steam discharged per minute per square foot of fire grate.

The guides, or wings, of the valve would reduce the clear opening by full one-ninth, for which no allowance has been made in the above.

James Brownlee, one of the committee of the Institution of Engineers and Ship-Builders, in Scotland, in his experiments on safety-valve openings, found that with a square-edged entrance, the flow of steam was reduced from 12 to 14 per cent. The safety valve, as generally made, cannot be considered as presenting a much better entrance to the steam than a square-edged orifice. In making this 14 per cent allowance, the weight in pounds of steam discharged per minute per square inch of opening, with square-edged entrance, corresponds very nearly with three-fourths of the absolute pressure in the boiler, as long as that pressure is not less than 25.37 pounds. Examples of this are shown in the following table:

Absolute Pressure in Pounds per square inch.	Weight discharged per sq. inch of orifice, with rounded entrance, per minute.	Weight discharged per minute with square-edged orifice.	Three-fourths of Absolute Pressure.
$P+15$	w^1	w^2	$\frac{3}{4}P+15$
25.37	22.81	19.6	19
30	26.84	23	22.5
40	35.48	30.5	30
45	39.78	34.2	33.8
50	44.06	37.9	37.5
60	52.59	45.2	45
70	61.07	52.5	52.5
75	65.30	56.1	56.2
90	77.94	67	67.5
100	86.34	74.3	75

The area of opening requisite to the discharge of any given constant weight of steam, it will be observed, is very nearly in the inverse ratio of the pressure. Thus, while 3 square inches of opening, with square-edged entrance, will discharge $3 \times 23 = 69$ pounds weight of 30 pounds pressure per minute, 1 square inch of opening will discharge 67 pounds per minute of 90 pounds pressure of steam.

The quantity of heat, however, requisite to generate (from water at 100°) 67 pounds weight of steam, at 90 pounds pressure, is only 1 per cent less than is required to evaporate 69 pounds at 30 pounds pressure. The boiler which will generate 69 pounds of steam per minute at 30 pounds, cannot, therefore, possibly generate more than 67.7 pounds at a pressure of 90 pounds; but many experiments on record seem to indicate that the deficiency at the higher pressure is more than *ten per cent.*

In ordinary marine practice there is not often more than 20 pounds of coal consumed per hour per square foot of fire grate, and the water evaporated seldom exceeds 9 pounds per pound of coal, which corresponds to 180 pounds per hour, or an evaporation of 3 pounds per minute per square foot of fire grate. Under these conditions, the area of the opening requisite to discharge all the steam a boiler can generate, corresponds to four times the square feet of fire grate, divided by the absolute pressure ($p+15$),

$$\text{or} \quad A = \frac{4\,G}{p+15}$$

Rule.—1st. Multiply the square feet of the fire grate by the number 4.

2d. To the steam pressure add the number 15.

3d. Divide the first by the second, and the quotient will be the area in square inches.

The English Board of Trade allowance is half of one square inch area of safety valve for each square foot of fire grate. Hence, the lift of valve is propor-

tional to the diameter, and, inversely as the pressure. For a discharge of 8 pounds per minute per square foot of fire grate, the requisite lift in inches is twice the diameter of a (flat-faced) valve, divided by the absolute pressure. This, however, does not apply to pressures less than 25 pounds (10 pounds per gauge, plus 15).

Take, for example, a safety valve 5 inches in diameter=19.6 square inches in area, which corresponds to $2\times19.6=39.2$ square feet of fire grate, which would evaporate $39.2\times8=117.6$ pounds of water per minute. Then, since the area A in square inches requisite to discharge any weight w in pounds of steam per minute at the pressure $p+15$, is

$$A=\frac{4\,w}{3\,(p+15)}$$

We would have, by taking the pressure $p=45$, and the weight $w=117.6$, the area

$$A=\frac{4\times117.6}{3\,(45+15)}=2.61 \text{ square inches,}$$

which corresponds to the opening of a flat-faced valve, 5 inches in diameter, when lifting.

$$\text{Lift } h=\frac{2\times5}{60}=0.1667$$

The circumference of a 5-inch valve being 15.7 inches, and $15.7\times0.1667=2.61$ square inches of opening, as stated.

When the angle of sit of the valve is 45°, the lift required in inches is

$$\text{Lift } h=\frac{2.8\,D}{p+15}$$

When a boiler is regularly fired, and all the steam generated discharged through an ordinary safety valve, under a succession of different pressures, the

lift of valve, multiplied by these absolute pressures, should be a constant quantity, provided the same quantity of heat is constantly entering the boiler, and provided, also, that the absolute pressure in the boiler, or the pipe below the valve, is not less than 1.726 times the absolute pressure of the steam in the chamber above the valve. In actual experiment a deficiency is generally manifested at the higher pressures. Hence, the suspicion of some considerable loss of heat at the higher temperatures. It has been suggested that this might be accounted for by the low-pressure steam carrying water along with it—retarding its motion—and thereby requiring a larger opening; but this would only aggravate the case, since the same opening will permit of a much larger quantity of *heat* being discharged from the boiler with wet than with dry steam. This phenomenon may be suggested as one worthy of further investigation.

According to the Prussian law, and allowing 36 square feet of heating surface per square foot of fire grate, the area A of safety valve is

$$A=\frac{36\,G}{p+15}$$

A valve of this size, when full open, is capable of carrying away nine times the quantity of steam generated at the pressure $p+15$, and therefore will, at the designated pressure $p+15$, be able to discharge all the steam by lifting $^1/_{36}$ part of its diameter.

At absolute pressure of (57+15) 72 pounds, the British and Prussian laws prescribe precisely the same area of valve. Take, for example, 20.36 square feet of fire grate, which requires, by British rule, a valve 10.18 square inches in area, equal to 3.6 inches diameter, and which, if flat-faced, would, at a pressure of 72 pounds, require to lift

$$h=\frac{2\times 3.6}{72}=^1/_{36}\text{ of an inch.}$$

Thus, by the Prussian rule, the area of valve is,

for 20.36 square feet of grate and 72 pounds absolute pressure,

$$A=\frac{36\times 20.36}{72}=10.18 \text{ square inches,}$$

equal to 3.6 inches diameter; and the requisite lift is (diameter 3.6) as before:

$$h=\frac{3.6}{36}={}^1/_{10} \text{ of an inch.}$$

The circumference of this valve being 11.31 inches, would (if flat-faced), by lifting $h={}^1/_{10}$ of an inch, give a clear opening of 1.131 square inches, which would, at 72 pounds absolute pressure, discharge $\frac{1}{2}\times 72\times 1.131=61.07$ pounds of steam per minute, and which corresponds to 3 pounds per square foot of fire grate—as $20.36\times 3=61.08$.

At absolute pressures of 36 pounds, the Prussian law prescribes double, and at 144 pounds only half the area of the British.

At all pressures above 1.726 atmospheres, the area of valve, when full open, by Prussian rule, is nine times that requisite to discharge all the steam generated, while by the British rule it is four and a half times at 36 pounds pressure, and eighteen times more than is required at 144 pounds absolute pressure; and this is after allowing for an evaporation of 8 pounds of water per minute per square foot of fire grate, which is considerably more than is usually realized in marine practice.

Before the ordinary valves rise and give sufficient opening, the pressure of steam frequently greatly exceeds the load under which the valve begins to rise. Hence, the requirement of large areas. With a properly-constructed valve, however, such as many now in use, which rise one-fourth of their diameter by an increment of 1 to 3 pounds above the load, there is no necessity for the area being much (if any) more than one-ninth of that prescribed by the Prussian rule.

Say, area $A = \frac{4\,G}{p+15}$ plus the area of wings of valves.

The valves here referred to are so very small that the stems, or wings, occupy a considerable proportion of the area, and must, in the above equation, be allowed for. These small valves give much more prompt relief to the boiler, and never permit the pressure to rise much beyond the load.

PRIZE FOR SAFETY-VALVE COMPETITION.

The editor of the *Nautical Magazine*, London, England, in March, 1872, offered a reward of £100 ($500) for the best 3-inch spring safety valve suit-

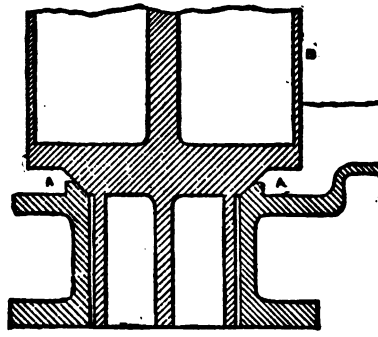


Fig. 19.—The Rochford Safety Valve.

able for high-pressure marine boilers. There were five safety valves entered for trial. The boiler upon which they were all tested, under the conditions of the trial, was 33 feet long, 7 feet 2 inches in diameter, of the Lancashire type, having two internal flues about 32 inches diameter each, inside, in which the fire grate was placed, as in marine boilers; the total area of grate surface was about 30 square feet.

The Rochford safety valve (Fig. 19) was awarded the prize. It will be seen that it has a projecting lip A, and the spring is enclosed in a case B, which can be filled with oil, if desired, for the preservation f the spring.

The editor, commenting on the trials, says, notwithstanding its absence of novelty, it would appear that an ordinary simple valve, well made, with true and narrow seating, and *long feathered wings*, moving freely in a long, truly-bored guide, meets the practical requirements so far as the valve and its seating are concerned.

For the loading of a spring valve, it would appear that a light, direct spring, with great range of elasticity, no friction, and a minimum amount of inertia, are the best means. These essential and sufficient conditions imply no novelty, and no delusive ingenuity.

In the trials, the valves were set to blow at 60 pounds per square inch, and the result was in favor of the Rochford safety valve. The umpires say, in their general remarks: "We could not raise steam above 63¼ pounds pressure by this valve. Reduced boiler pressure; stopped blowing off at 60 pounds exactly."

One of the umpires remarked that he thought the Board of Trade were right enough in not adopting any of the spring safety valves yet put forward; but he could not agree in any condemnation of the spring principle, though he did not himself, as at present minded, like it as well as the dead weight; and he added, that if a more reasonable area of valve were asked than half an inch to the square foot, it would be hard (while lock-up valves are asked) to beat the old dead-weight system. The steam that is wasted in rolling, is, he said, nothing to that wasted in the continual leakage, rolling or quiet, from the huge valves which he appears to think are required by the Board of Trade.

It would appear, from the remarks of this umpire, that efficient, small, dead-weight safety valves are required, rather than ordinary valves spring-loaded.

The results of these trials seem to confirm the convictions of the arbitrators that a safety valve can hardly be too simple and direct in its action and arrangement.

During the year 1874, the Glasgow engineers ap-

pointed a committee to investigate the subject of safety valves. In January, 1875, they came to an agreement on certain recommendations. A difference of opinion on a certain "pop" valve had delayed an earlier acquiescence.

The editor of the *Nautical Magazine*, seeing that his efforts in 1872–74 were attended with very successful results in calling into existence and competition many useful safety valves, and seeing that by the exertions of the Board of Trade officers very much useful information and accurate knowledge has since been disseminated and fully confirmed by the experiments afterwards made by the Glasgow engineers, and elsewhere, it has occurred to the present editor that he may be successful in calling forth further latent talent, and stimulating invention, by offering a further prize.

Eight safety valves entered for the editor's prize of £100 (or $500), and Fig. 20 shows the safety valve, Vena Contracta, for which the prize has been awarded. Owing to the sad death of the secretary of the Committee of Umpires, the details of the test cannot be given, but the following details concerning the performance of the successful valves are stated.

Conditions of the Test.

Diameter of valve in inches	8
Diameter of waste pipe in inches	8
Area of fire grate in square feet	14
Rate of combustion per square foot of grate per hour in pounds	20
Rate of evaporation per pound of coal	8.75
Temperature of feed water (constant) in degrees	100
Temperature of waste gases in smoke box	670
Steam pressure at which the valve was loaded, in pounds	60
Steam pressure in box above valve while blowing, in pounds	4
Steam pressure in waste pipe 4 feet above the valve, in pounds	2
ration of test, in hours	1

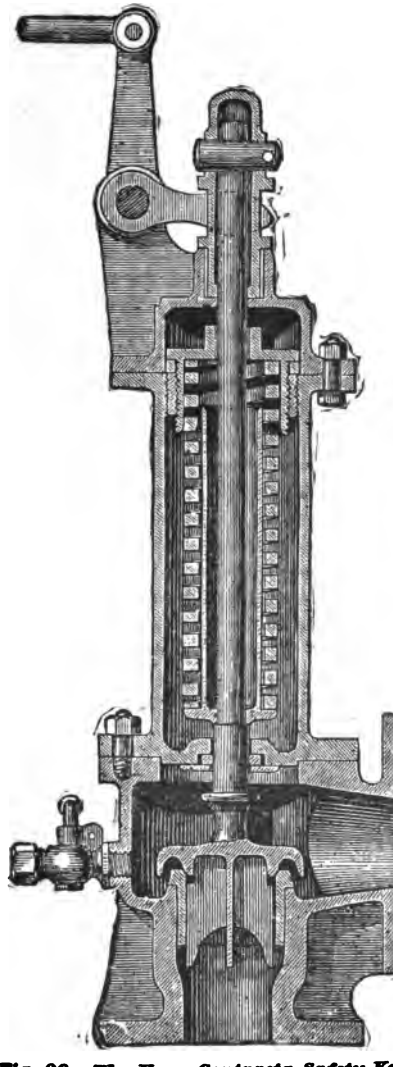


Fig. 20.—The Vena Contracta Safety Valve.

The whole of the steam generated had to pass through the valve, and the following is the result: One gauge, showing 60 pounds per square inch, the valve went off. The gauge instantly started to go gradually back to 59.4 pounds, when the valve closed tight, the time occupied being 13 seconds, and the mean difference between the greatest and least steam pressure being 0.6 of a pound (there being no accumulation whatever). The valve repeated this cycle of operation, during the hour's test, with unvarying regularity of pressure and time. The time was taken simultaneously by all the arbitrators from a 15-inch diameter dial clock, fixed on the wall, having a second hand moving around its periphery, and they were unanimous in awarding the prize to Vena Contracta, which has since been claimed as the valve of Thomas Adams, of Manchester.

A trial of safety valves was also made in 1874, before the chief surveyor of the Board of Trade and the chief of the Marine Department of England, to test the proper area to relieve boiler pressure. The first trial was on a marine tubular boiler of the following dimensions: Diameter, 9 feet 9 inches; length, 19 feet 8 inches, with four furnaces 7 feet 8 inches long by 2 feet 10¼ inches in diameter, with a total grate surface of 75 square feet, and 2,800 square feet of heating surface.

This boiler was fitted with two ordinary safety valves, 5 inches in diameter, having a total area of about 39 square inches, and loaded to 60 pounds per square inch pressure by direct weight—in the aggregate 2,340 pounds.

An improved valve was also placed on this boiler, having a diameter of 2½ inches, with an area under 4 inches, and loaded by direct weight to 50 pounds per square inch. The total weight on this valve was under 200 pounds, and the valve relieved the boiler of all the steam that could be generated, as the following will show: At the commencement of the trial the hight of the water was 5 inches in the gauge glass, the pressure of steam was 48 pounds, the fires very strong, and forced in a similar manner to steam-

ing at full speed. When the steam had risen to 50 pounds, the valve began to rise and steam to escape; three minutes after the pressure was 51 pounds, and the valve was full open—namely $^{3}/_{16}$ of an inch. After another period of two minutes, the hight of the water in the glass was 3½ inches, and the pressure of steam 52½ pounds; after another period of five minutes, the hight of the water was 2 inches in the glass, and the pressure of the steam 56 pounds per square inch; after another period of five minutes, the hight of the water was one inch in the glass, and the pressure of steam still at 56 pounds; after another period of one minute, the engines having been moved, the pressure was reduced to 51 pounds, and the valve began to close, and as the ship was obliged to move, the steam was let into the engines, when at 49½ pounds the valve closed. The fires were forced during the whole period of the trial with the boiler feeds, and all connections shut off; the water was steady in the glass gauge, and no water escaping by the waste steam pipe.

The next experiment was on the same boilers with the ordinary valves, being two of 5 inches diameter each, equaling a total area of 39.26 square inches, loaded by dead weights of 2.355 pounds to a pressure of 60 pounds per square inch. The steam rose until these valves began to blow at 60 pounds; the fires were then forced, to get as much steam as possible, and at the end of 11 minutes (at which time the engines commenced to move again) the steam had risen to 68 pounds.

From the above two experiments, it would appear that a 2½-inch valve is hardly large enough to discharge all the steam that this large boiler was capable of generating, at a pressure of 50 pounds; but at 60 pounds it possibly would, for, during the last five minutes, the fires were, if anything, better than at first, and the steam remained at 56 pounds *for five minutes.* The small range of pressure between that at which the valve lifted *full open*, and that at which it closed altogether, is worthy of remark.

A further trial of the same 2½-inch valve was made

on another marine tubular boiler, 12 feet 6 inches in diameter, 10 feet 8 inches in length, with three furnaces 6½ feet long by 34 inches in diameter, having a total grate surface of 46½ square feet. This boiler was fitted with two ordinary safety valves of 8½ inches in diameter each, having a total area of about 28½ square inches, and loaded to 70 pounds pressure by levers and weights.

The improved valve was loaded, by direct weights, to 60 pounds per square inch, and relieved the boiler, as the following table will show:

	P.M.	Pressure in pounds.
Trial commenced	2.35	
Valve began to lift	2.37	58½
	2.38	59
Valve blowing freely	2.40	60
Full open	2.45	61
	2.50	62
	2.55	62
	2.30	63

The fires were in proper order during the trial, clear steam and no water escaping from the waste steam pipe; but the hight of the water was not taken on this trial, as it was not steady in the glass, doubtless caused by the boiler having been filled with dirty water from the dock. The lift of the valve during this trial was regulated to $^{7}/_{16}$ of an inch, previously to the commencement of the trial. It will be observed that, on the previous trial, the lift was regulated to $^{9}/_{16}$ of an inch.

A third trial, on the same boiler, at a reduced pressure of 50 pounds, was made to test its rising and falling properties, when it was found that the valve had risen to the regulated lift of $^{7}/_{16}$, at a pressure of 52½ pounds, and when the pressure was reduced to 47½ pounds the valve had closed.

These trials were witnessed by Mr. Traill, chief surveyor to the Board of Trade, and Mr. Bisset, assistant principal surveyor for Liverpool.

The editor of the *Nautical Magazine* says that the trials of safety valves for the prize of $500, show

conclusively that a long spring, which is nobody's patent, is the best sort of spring if a spring is to be used at all; and the trials of the improved safety valve, as before stated, go far towards proving that a single 2½-inch safety valve is almost sufficient, when properly constructed, to relieve a 100 horse-power boiler of four furnaces, with hard firing. The valve may be loaded with anybody's spring, or with dead weights, as the fancy of the ship-owner may elect. We cannot, of course, expect the Board of Trade to allow at once a solitary 2½-inch valve to take the place of two 5 inch valves on a large marine boiler, as such a proceeding would be in direct violation of established engineering practice; but we venture to suggest to ship-owners that they might reasonably ask the board to allow, by way of experiment, *two* 2½-inch improved valves on boilers of 100 horse-power and upwards, in order that the experiments we have been at the pains to witness and record may be repeated and verified.

From the examination of the improved valve (Samson and Parker's), and the results of the trials, it would appear that this valve has done its work sufficiently well to warrant us in expressing a belief that two valves would be ample to relieve a boiler of 100 horse-power. We should remark, that this valve has no rubbing or bearing surfaces beyond what is necessary for a common valve, and appears to be as simple, and as easily kept in repair, as a valve of the common kind of the same diameter, and certainly much easier than the 6 or 8 inch common safety valves now in use on some high-pressure boilers.

If this improved valve can—as we say it can—do the whole work with such a remarkably-diminished area, then it is doubtful whether dead weights will not be better than springs.

SAFETY-VALVE LIFTS.

The hight of the lift of a safety-valve governs the diameter of the valve. To find the lift, we must know the weight of steam (water) in pounds which

will escape through an orifice in the boiler having an area of one square inch. This in ordinary practice, is very nearly fifty times the pressure of the steam measured from the absolute zero pressure. The area of opening, therefore, for any boiler must be, in square inches, the weight of water evaporated per hour as a maximum, divided by fifty times the absolute pressure.

The absolute steam pressure above vacuum is the steam pressure as shown by a steam gauge, plus (+) the pressure of the atmosphere, which is on an average 15 pounds (14.7 pounds exact) per square inch. The formula will be as follows:

$$Æ = \frac{\text{lbs.}}{50\,(p+15)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

Where $Æ$ = the effective area of outlet.

p = steam pressure as shown on steam gauge.

lbs. = pounds of water (maximum) evaporated per hour.

15 = pounds average atmospheric pressure.

Rule.—1st. To the steam gauge pressure add 15; multiply this sum by 50.

2d. Divide the number of pounds of water evaporated per hour by the product of the first, and the quotient will be the effective area ($Æ$) in square inches.

Example.—A boiler evaporating 600 pounds of water per hour, what area of opening should the safety valve have, so that the steam pressure shall not exceed 80 pounds per square inch on the steam gauge?

$$\text{By formula: } Æ = \frac{\text{lbs.}}{50\,(p+15)}$$

$$Æ = \frac{600}{50\text{-}(80+15)} = 0.126 \text{ square inches.}$$

or,

Pressure per steam gauge $80+15\times50=4{,}750$.

$$\frac{600}{4,750}=0.126 \text{ square inches area.}$$

United States Rule.

Board of Supervising Inspectors of Steam Vessels.

$$Æ=D+l+2\times 8.1416\times l-0.29.$$

l=lift of valve, in hundredths of an inch.

D=diameter of valve, in inches.

Rule.—1st. To the diameter of the valve add one-half the lift.

2d. Multiply this number by 8.1416, and the last product by 0.71 of the lift, for the effective area.

The conditions incident to this rule are: Diameter and lift are given; angle of inclination of valve sit must be 45° to the center line of its axis; valve must not rise out of its sit, or above a line perpendicular to its angle of inclination, and meeting the upper edge of the sit and the lower edge of the valve. When a valve rises above a line perpendicular to its angle of inclination, the amount of area so obtained is found by the following rule:

Rule 2.—Multiply the diameter of the valve by the additional lift, and by 8.1416. Add this last product to the first, for the whole effective area.

In case the sit of the valve is flat, at an angle of inclination of 90° to the center line of axis, the effective area is found by Rule 2, leaving out the word "additional" and the last clause of the rule.

Rule 1 based upon the formula applied to finding the surface of a frustum of a cone, the upper base of which is equal to the diameter of the valve, the lower base equal to the diameter plus (+) the lift of the valve, and the slant hight equal to 0.71 of the lift.

In the trials made at the Washington navy yard, September, 1875, it was found: That the diameter of a safety valve is not an infallible test of its efficiency; that the lift which can be obtained on a safety valve, other conditions being equal, is a test of its efficiency; that the lift of a safety valve de-

pends upon the velocity and weight of the escaping steam; that two-tenths of one inch is the maximum lift to be obtained on a common lever safety valve.

In these trials, it was found that two-tenths of an inch was all that any of the valves could be forced from their seats without a considerable increase in the pressure, equaling, in the case of a valve with an area of 5 square inches, at 10 pounds pressure, 110 per cent excess. To get any considerable increase in the lift, it is necessary to increase the pressure in a greater ratio than that of the lift. This is but reasonable to suppose, when we consider that as soon as a valve begins to leave its sit new conditions are

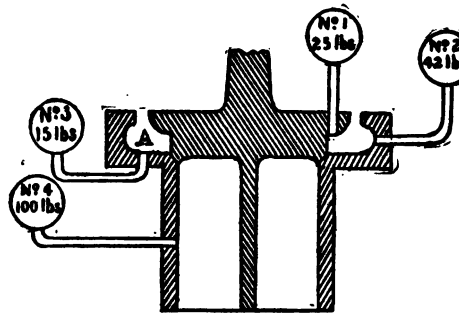


Fig. 21.—Adams' Experimental Safety Valve.

introduced. The high velocity with which the steam escapes reduces the pressure at and near the orifice of escape, and its dynamical effect upon the increased area of the valve is not that due the pressure when acting upon the valve at rest.

Thomas Adams, of Scotland, constructs a valve with a projecting lip A, as shown in Fig. 21. By applying steam gauges at the points shown on the the sketch, he observed that they gave the indicated readings at the time the valve opened, and that then the pressure began to lower, around the valve first, and lastly in the boiler, when the valve suddenly closed.

In the navy yard trials, six safety valves were ex-

perimented on, and all of them, with the exception of the one with an area of 5 square inches, at the pressures of 10 and 20 pounds, afforded sufficient effective areas to discharge the weight of steam generated, and by the following comparison it will be found that the lifts and areas of the several valves decreased from the lowest to the highest pressure in nearly an exact proportion, the difference being less than one per cent, viz.:

	Decrease of lift from					
5-inch,	10 to 100 lbs.,	75—	of areas	76—	per cent.	
10-inch,	10 to 100 "	70—	"	71—	"	
15-inch,	10 to 100 "	82+	"	88—	"	
20-inch,	10 to 80 "	82+	"	83—	"	
25-inch,	10 to 80 "	73+	"	74—	"	
30-inch,	10 to 80 "	88—	"	88—	"	

The committee found that when very large valves of the common form were used, their action was not satisfactory, as at high pressures the lift is scarcely noticeable. It was found that no practical results could be obtained on the experimental boiler by going above 80 pounds pressure with the larger valves. On a trial of the valve with 30 square inches area at 100 pounds pressure, it hardly rose at all from its sit, but appeared to *tilt*, alternately from one side to the other, sufficient to allow all the steam to escape that the boiler was capable of generating. It was also found that the lift of the valve of 30 square inch area, at a steam pressure of 80 pounds, was only 0.02 of an inch.

Fig. 22 represents the lever safety valve used in these experiments. This safety valve was carefully constructed, with knife-edges for the fulcrum and valve stem, as shown in the figure. It was found, in experimenting with these safety valves, that the lift decreased as the steam pressure at which the valve was loaded was increased; and by taking these areas of opening, the committee arrived at the following rule for calculating the area of opening, in square inches, required to discharge a given weight of steam per hour:

Let Æ=effective area in square inches.
lbs.=pounds of water evaporated in one hour.

Then, at a steam pressure of

10	pounds per square inch,	Æ=lbs.	0.0011
20	" "	Æ=lbs.	0.0010
30	" "	Æ=lbs.	0.0009
40	" "	Æ=lbs.	0.0008
50	" "	Æ=lbs.	0.0007
60	" "	Æ=lbs.	0.0006
70	" "	Æ=lbs.	0.0005
80	" "	Æ=lbs.	0.0004
90	" "	Æ=lbs.	0.0003
100	" "	Æ=lbs.	0.0002

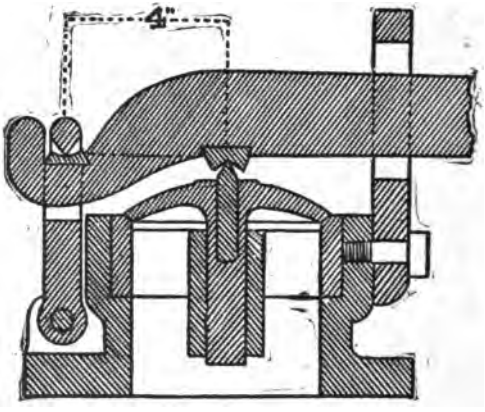


Fig. 22.—Common Lever Safety Valve Used on the Trials.

The committee say that in the arrangement of safety valves for any boiler, or set of boilers, that a number of safety valves are preferable to one with a large area; and they do not believe it advisable to employ a common lever safety valve, with either a beveled or flat sit, of more than 10 square inches area (say, 3.5 inches diameter). According to their experiments, the lifts of the lever safety valve, when discharging at different pressures, two 3.5 inches diameter valves will discharge *four thousand* pounds

of steam (water) in one hour, at all steam pressures from 20 to 100 pounds per square inch; and from which the committee derived the following rule for calculating the area of valve that will give the required area of opening for any particular case:

Multiply the number of pounds of water evaporated per hour by the number 0.005; the product will be the area (A) of the valve in square inches.

The Scotch committee recommend that the lift of the valve in all cases will be equal to their diameters divided by the constant number 36.

THE BEST FORM FOR A SAFETY VALVE.

A safety valve, when raised, presents a greater area to the steam pressure than when closed. Hence, it would be expected that it would open wide, due to the action of the steam pressure on this increased area. But in practice this is found not to be the case; all experiments show that the common lever safety-valve lift is very small when the pressure for which it is loaded is reached. At the Washington Navy Yard experiments it was found, as before stated, that two-tenths of an inch was the maximum lift on the common lever safety valve.

The committee made trial of twenty two safety valves sent to be tested; but twelve of them passed a full trial, with two common lever safety valves furnished by the committee. From the experiments made, it was found that the patent safety valves with larger areas of openings than the common lever valves allowed the pressure to increase full as much as the latter. This was, no doubt, due to the complicated forms by which the excessive lift was accomplished, and made it more difficult for the escape of the steam, rendering it necessary to have larger openings for the same weight of steam. The results with the same valve showed great variation in some of the trials. The excessive difference was due to a proper adjustment, and when properly adjusted the best results were obtained. This was the case with both the special and common lever forms.

During these experiments, it was noted that with

the common lever form of valves, when the valve opened, the pressure gradually increased to the maximum when the boiler was forced; and when the pressure began to fall, they closed at the points indicated. In the case of all the special form of valves, after the valve opened, the pressure fell below the opening point, the valve sometimes closing several times, and the pressure falling below the opening point several times during the duration of the trial, and sometimes the pressure immediately fell and the valve blew off at a pressure less than that at which it was set during the whole trial.

The following table gives the results of the differ-

LOADED TO OPEN AT 30 POUNDS.

NAME OF VALVE.	Area of Valve in square inches.	Lift of Valve in inches.	Effective area of Valve in square inches.	Commenced to blow at pounds pressure per square inch.	Open wide in pounds pressure per sq. in.	Seated at pounds pressure per sq. in.	KIND OF OF VALVE ON TRIAL.
Borden.....	7	0.19	1.11	29	30	26	Combination.
Cockburn.....	5	0.23	1.82	29	30	27	Disk.
Crosby.....	5	0.12	1.257	29	30	28	Reactionary.
Clemens.....	5	0.2	1.171	28	30	28	Combination.
Chamberlain..	5	0.25	1.58	29	30	28	Reactionary.
Hodgin.....	5	0.37	2.934	25	30	26	"
Lynde.....	5	0.14	1.11	29	30	27	Disk
Morse.....	5	0.10	1.42	29	30	27	Annular.
Orme.....	5	0.08	0.457	29	30	30	Reactionary.
Richardson....	5	0.25	1.455	29	30	29½	"
Rochow.....	5	0.21	1.231	28	30	28	Piston.
Common lever.	5	0.16	0.929	29½	30	29½	Disk.
" "	10	0.18	1.469	29½	30	30	"

LOADED TO OPEN AT 70 POUNDS.

Borden.....	7	0.10	0.574	60	70	67½	Combination.
Cockburn.....	5	0.15	1.18	69	70¼	68½	Disk.
Crosby	5	0.65	0.729	69	70½	66	Reactionary.
Clemens.....	5	0.20	1.171	65	70	65	Combination.
Chamberlain..	5	0.13	0.920	68	70	67½	Reactionary.
Hodgin.....	5	0.18	1.427	65	70	56	"
Lynde.....	5	0.07	0.555	69	70	67	Disk.
Morse.....	5	0.6	0.84	69	70	50½	Annular.
Orme.....	5	0.05	0.284	69	70	61	Reactionary.
Richardson...	5	0.12	0.691	69½	70	67	"
Rochow.....	5	0.21	1.231	69	70	64	Piston.
Common lever.	5	0.11	0.633	69	70	68	Disk.
" "	10	0.09	0.725	69	70	68¾	"

ent valves which passed a full trial—12 in number. Each safety valve was in turn attached to the boiler, and was loaded to blow off at 30 pounds steam pressure, and was operated for ten minutes, with a strong fire in the boiler. The steam pressure was then increased to 70 pounds per square inch, and the experiment repeated.

It will be seen from the above table that the patent safety valves, with larger areas of openings than the common lever valves, allowed the pressure to increase fully as much as the latter. This was, no doubt, due to the complicated forms by which the excessive lift was accomplished, and made it more difficult for the escape of the steam, rendering it necessary to have larger openings for the same weight of steam. With the same valve, where the table shows considerable difference, the results were due to a want of proper adjustment of the valve, which, when remedied, the best results were obtained.

With the common lever safety valves, when the valve opened, the pressure gradually increased to the maximum when the boiler was forced, and when the pressure was allowed to fall, it closed at the points indicated. With nearly all the other valves, however, after the valve opened, the pressure fell below the opening point, the valve sometimes closing several times, and the pressure falling below the opening point several times in the course of a ten minutes' trial; and sometimes the pressure fell at once, and the valve blew off at a less pressure than that at which it was set during the whole trial. This peculiarity is important and not a desirable feature in a safety valve, and the records of these trials fully confirm the opinion of engineers generally that the common lever safety valve, when properly made, is not excelled for the relief of the excess of steam pressure in a boiler.

It is a paradox, that a safety valve at a high steam pressure will lift less in hight than at a lower pressure. This is due to the well-known fact that the greater the pressure the greater the velocity at which the steam will flow through an orifice of given size;

the high velocity of the steam immediately under the valve will, by the temporary reduction of the volume there, and the consequent reduction of local pressure, cause the valve to sink lower before finding a position of equilibrium. (See tables of the experiments at the Washington Navy Yard). The area of opening of the Crosby safety valve, at 80 pounds steam pressure, was 1.257 square inches, and at 70 pounds, 0.729 of a square inch, being 0.528 of a square inch difference. With the common safety valve at 80 pounds pressure, the area was 0.929 of a square inch, and at 70 pounds pressure 0.633 of a square inch, being 0.296 of a square inch difference.

In the report on safety valve tests, made in 1875 at the United States Navy Yard, Washington, D. C., by a special committee of the Board of Supervising Inspectors of Steam Vessels, it is stated that an ordinary disk valve with a beveled sit, having an area of *ten* square inches, will discharge *two thousand* pounds of steam in an hour at all pressures from 20 to 100 pounds per square inch.

The following rule for determining the size of safety valves is deduced from these experiments:

Multiply the weight of water, in pounds evaporated in one hour, by 0.005; *the result is the area of the valve disk in square inches.*

It is likewise recommended that the area of safety valves should not exceed 10 square inches, and that several valves be employed when a larger area is required for a boiler.

These experiments proved that the ordinary disk valve is not only the simplest in construction, but the most reliable in its action and least liable to derangement. Disk valves are made either with a conical or with a flat sit. It is claimed for the latter, that they are less liable to stick, and that they present a larger opening, with the same lift, than the former. On the other hand, it is objected that it is more difficult to keep them tight, and that the steam escapes with greater difficulty through their opening, since it has to make two abrupt changes in direction. When a wide bearing surface is given to

flat-faced valves, they are apt to have a trembling, vibratory motion when they are discharging steam.

Conical valves are most usually employed, the bevel of their seat forming an angle of 45°. With a narrow face, the valve is more easily kept tight and the steam escapes with greater ease than with a wide face. Some authorities claim that a width of one-sixteenth of an inch is sufficient for the sit of a conical valve 4 inches in diameter. The valve and sit are generally made of composition metal. In some of the patent valves the bearing surfaces are formed by nickel rings let into the valve and sit.

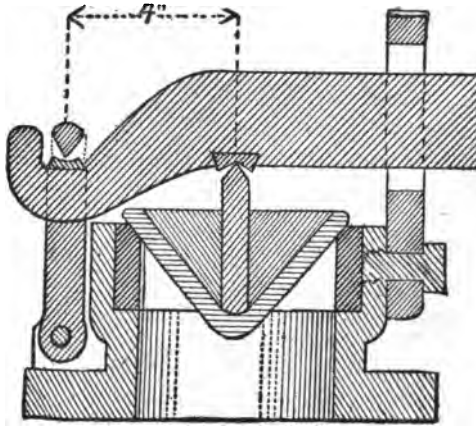


Fig. 23.

The valve is guided either by wings attached to the disk below its sit, or by a central spindle working in a sleeve. The opinions of competent engineers differ as to which of these two devices for guiding the valve is preferable; both are liable to cause the valve to stick when they are fitted too close, in consequence of the lodgment of dirt or scale, or of unequal expansion when steam is raised quickly.

To prevent the canting of the valve in consequence of the oblique thrust thrown upon it by the lever as it lifts, the central spindle upon which the lever

rests is often detached from the valve disk; the latter is hollowed out on the top, so that the point where the spindle rests upon the valve lies below the valve sit (see Fig. 23). When this spindle is rigidly attached to the valve disk, it is connected with the lever by means of a short link. The pins or bolts of the articulated joints of the lever and link are often made of composition, to lessen the liability of their becoming fast by rusting, or by getting clogged with grease and dirt. To reduce the friction as much as possible, it is best to make the lever turn on knife edges, case-hardened.

As will be noticed in Fig. 23, pins are not used

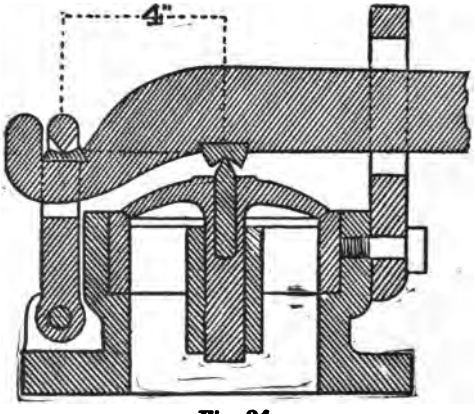


Fig. 24.

for the fulcrum, but knife edges are used, as shown, to transmit the pressure of the lever to the safety valve through a pin pointed at the bottom end. This arrangement is far preferable to that generally adopted where joint pins are used, and should come more generally into use.

The lever safety valve recommended by the Board of Supervising Inspectors of Steam Vessels, is represented in Fig. 24. The following directions are given regarding its construction:

All the points of bearing on the lever must be in the same plane. The distance of the fulcrum must

in no case be less than the diameter of the valve opening. The length of the lever should not exceed the distance of the fulcrum multiplied by 10. The width of the bearing of the fulcrum must not be less than ¼ of an inch. The lever of the fulcrum link should not be less than 4 inches. The lever and fulcrum link must be made of wrought iron or steel, and the knife-edged fulcrum points and bearings for the points must be made of steel, and hardened. The valve sit, and bushings for the stem or spindle, must be made of composition (gun metal) when the valve is intended to be attached to a boiler using salt water; but when the valve is to be attached to a boiler using fresh water, and generating steam of a high pressure, the parts named, with the exception of the bushings for the spindle, may be made of cast iron. The valve must be guided by its spindle, both above and below the ground seat, and above the lever, through supports either made of composition (gun metal) or bushed with it. The spindle should fit loosely in the bearings or supports. When the valve is intended to be applied to the boiler of steamers navigating rough waters, the fulcrum link may be connected directly with the spindle of the valve, provided always that the knife-edged fulcrum points are made of steel and hardened, and that the object sought by the link is obtained—namely, the vertical movement of the valve, unobstructed by any lateral movement. In all cases, the weight must be adjusted on the lever to the pressure of steam required in each case by a correct steam gauge attached to the boiler. The weight must then be securely fastened in its position, and the lever marked for the purpose of facilitating the replacing of the weight, should it be necessary to remove the same.

A PERFECT SAFETY VALVE.

A perfect safety valve is one which will rise as soon as the pressure at which it is set is attained, that will prevent the pressure increasing if the boiler is forced to its utmost extent, and that will close promptly as soon as the pressure commences to fall.

With all the experience of engineers, it seems impossible to design a valve possessing all the above features; but no doubt it can be closely approximated to.

TABLE OF AREAS OF VALVES OF DIFFERENT DIAMETERS.

Diameter of Valve. Fractions.	Diameter of Valve. Decimals.	Circumference of Valve in Inches. Decimals.	Area of Valve in Square Inches. Decimals.
1/32	0.03125	0.0981	0.00076
1/16	0.0625	0.1963	0.00306
1/8	0.125	0.3926	0.01227
3/16	0.1875	0.5890	0.02761
1/4	0.25	0.7854	0.04908
5/16	0.3125	0.9817	0.07669
3/8	0.375	1.1780	0.1104
7/16	0.4375	1.374	0.1503
1/2	0.5	1.578	0.1963
9/16	0.5625	1.767	0.2485
5/8	0.625	1.963	0.3067
11/16	0.6875	2.159	0.3712
3/4	0.75	2.356	0.4417
13/16	0.8125	2.552	0.5184
7/8	0.875	2.748	0.6013
15/16	0.9375	2.945	0.6902
1	1	3 1416	0.7854
1 1/16	1.0625	3.3379	0.8861
1 1/8	1.125	3.5343	0.9940
1 1/8	1.1283	0.000	1
1 3/16	1.1875	3.7306	1.1075
1 1/4	1.25	3.9270	1.2271
1 1/4 Full.	1.2611	3.9564	1.25
1 5/16	1.3125	4.1233	1.3529
1 3/8	1.3667	4.2945	1.4625
1 3/8	1.375	4.3197	1.4848
1 3/8	1.382	4.3394	1.5
1 7/16	1.4375	4.5160	1.6229
	1.4912	4.6817	1.75
1 1/2	1.5	4.7124	1.7671
1 9/16	1.5625	4.9087	1.9175
	1.5957	5.0083	2
1 5/8	1.625	5.1051	2.0789
1 11/16	1.6875	5.3014	2.2365
	1.692	5.3128	2.25
1 3/4	1.75	5.4978	2.4053
	1.7823	5.5954	2.5
1 13/16	1.8125	5.6941	2.5801
	1.86	5.8407	2.75
1 7/8	1.875	5.8905	2.7611
1 15/16	1.9375	6.0868	2.9483
	1.9587	6.1324	3

Diameter of Valve. Fractions.	Diameter of Valve. Decimals.	Circumference of Valve in Inches. Decimals.	Area of Valve in Square Inches. Decimals.
2	2	6.2832	3.1416
	2.034	6.3867	3.25
$2\frac{1}{16}$	2.0625	6 4795	3.3411
	2.1105	6.6254	3.5
$2\frac{1}{8}$	2.125	6.6759	3 5465
	2.1838	6.8452	3.75
$2\frac{3}{16}$	2.1875	6.8722	3 7583
$2\frac{1}{4}$	2.25	7.0686	3.9760
	2.256	7.069	4 .
$2\frac{5}{16}$	2.3125	7.2649	4.2001
	2.3248	7.2848	4.25
$2\frac{3}{8}$	2.375	7.4613	4.4302
	2.3934	7.5040	4.5
$2\frac{7}{16}$	2.4375	7.6576	4.6664
	2.4416	7.6616	4.75
$2\frac{1}{2}$	2.5	7.8540	4.9887
	2.525	7.9280	5
$2\frac{9}{16}$	2.5625	8.0503	5.1573
	2.5842	8.1012	5.25
$2\frac{5}{8}$	2.625	8.2467	5.4119
	2.646	8.3084	5.5
$2\frac{11}{16}$	2.6875	8.4430	5.6727
	2.7049	8.4937	5.75
$2\frac{3}{4}$	2.75	8.6394	5.9395
	2.7636	8 6758	6
$2\frac{13}{16}$	2.8125	8 8357	6.1226
	2.82	8.8548	6.25
$2\frac{7}{8}$	2.875	9.0321	6.4918
	2.8764	9.0365	6.5
	2.9305	9.20	6.75
$2\frac{15}{16}$	2.9375	9.2284	6.7772
	2.9835	9.3666	7
3	3	9.4248	7.0686
	3.0365	9.5330	7.25
$3\frac{1}{16}$	3.0625	9.6211	7.3662
	3.0884	9.6963	7.5
$3\frac{1}{8}$	3.125	9.8175	7.6699
	3.139	9.8596	7.75
$3\frac{3}{16}$	3.1875	10.0138	7.9798
	3.19	10.0166	8
$3\frac{1}{4}$	3.25	10.2102	8.2957
	3.288	10.3243	8.5
$3\frac{5}{16}$	3.3125	10.4065	8.6179
$3\frac{3}{8}$	3.375	10.6029	8.9462
	3.384	10.6257	9
$3\frac{7}{16}$	3.4375	10.7992	9.2806
	3.47	10.8958	9.5
$3\frac{1}{2}$	3.5	10.9956	9.6211
	3.77	11.8378	10

Diameter of Valve. Fractions.	Diameter of Valve. Decimals.	Circumference of Valve in Inches. Decimals.	Area of Valve in Square Inches. Decimals.
4	4	12.5664	12.5654
	4.371	13.725	15
4½	4.5	14.1372	15.9043
4¾	4.75	14.9226	17.7205
5	5	15.7080	19.6350
	5.047	15.8475	20
5½	5.5	17.2788	23.7583
	5.642	17.7058	25
6	6	18.8496	28.2744
6	6.375	20.0175	30

SPRING-LOADED SAFETY VALVES.

I have in my former articles given a description of those safety valves which are held to their sits against internal pressure by weights, either acting directly or through levers, and which are most generally in use on stationary and marine boilers. I now propose to give the history of those which are held to their sits against internal pressure by springs, either acting directly or through levers, used almost exclusively upon locomotives, and to a great extent on portable and marine boilers.

As before stated, safety valves were employed by Papin in 1680, and are, therefore, two hundred years old, and, as shown, probably much older.

The objections to spring safety valves, are that the compression of the spring is increased with the lift of the valve, and therefore the pressure holding it down to its sit becomes greater the higher the lift, and as the weight of a dead load is constant for any hight of lift, the amount of lift of a given valve for any pressure would be less with a spring than with a constant weight. Therefore, boilers with spring-loaded safety valves should be loaded at a certain per cent below the blowing-off point; or, in other words, suppose a boiler should be allowed, according to law, to carry 100 pounds pressure per square inch, the spring on the valve, to lift the proper hight to free the boiler at that pressure, should be set at 95 pounds, as the accumulated pressure due to the increased compression of the spring will be 5 pounds; and as the valve would blow off at 95 pounds, that

would be the working pressure of the boiler, although the limit to which the pressure could accumulate would be 100 pounds per square inch.

Looking at it in this way, the strength of the boiler should be increased or the load upon it reduced, as compared with the practice of dead-loaded safety valves.

The amount of pressure accumulated with spring-loaded valves is a less percentage of the pressure the higher the pressure rises, and there is soon reached a pressure at which the percentage of accumulation becomes so small as to be of little practical importance.

In the United States navy yard experiments, made with spring valves, it was found that the percentage of accumulation at 34 pounds, was 19 pounds; at 59 pounds it was 9.4 pounds; at 80 pounds it was 6 pounds; and at 90 pounds it was 5 pounds.

With the advanced state of boiler engineering, the majority of good boilers have a factor of safety of *six*—that is to say, the working pressure of the boiler is one-sixth the bursting pressure. At 75 pounds per square inch working pressure, we have a bursting pressure of $75 \times 6 = 450$ pounds, and a percentage of accumulation upon the load pressure of the spring-loaded valve of say 8 per cent; that is, $75 \times 8 = 600$ pounds; $75 + 6 = 81$ pounds. The highest pressure to which steam can be carried in such a boiler, with a properly proportioned spring valve loaded to 75 pounds per square inch, is

$$\frac{450}{81} = 5.62, \text{ the factor of safety,}$$

leaving still an enormously large margin of strength before reaching the point of explosion.

The makers of spring-loaded safety valves argue that the pressure of accumulation is the same in dead-weight valves as in spring-loaded valves. If they will but stop and think for a moment, they will see that in the dead-loaded valves the resistance is constant, regardless of the lift of the valve; but with the spring-loaded valve, as commonly made, the

slightest proportion of lift compresses the spring, and the pressure, acting against this lift, varies directly with the amount of that lift. Therefore there can be no doubt that the pressure of accumulation is greater in the case of the spring-loaded than the dead-loaded valve, all circumstances being the same.

To overcome this increase of pressure as the valve rises, it is necessary to increase the area of the valve with its lift, or to arrange that the increased compression of the spring may be compensated in some other way. The form of valve shown in Fig. 25 has been put on the market to overcome the above difficulty.

If the contact between a safety valve and its sit were the contact of two sharp edges, like two circular knives edge to edge, the action of a valve in opening and closing would be simpler than it can generally be in practice. In fact, the surfaces in contact must have, for constructive reasons, a breadth very considerable in proportion to the diameter closed by the valve; and since the areas of circles are to each other as the squares of their diameters, the area of the circle circumscribed by the outer border of the valve sit is materially larger than the area bounded by the inner border of the valve sit. The smaller area alone, wholly within the sit, is acted on by the confined steam while the valve is closed; the larger area, within the outer border of the sit, is acted on by the escaping steam while the valve is open. It was, therefore, not unnatural to suppose that a safety valve, once opened against a resistance nearly constant, would then open more widely, so as to give free outlet to the steam, and that it would remain open until a very sensible reduction of pressure in the boiler should enable a force, at first overcome by the higher pressure on the smaller area, to overcome in its turn the reduced pressure on the larger area.

That the reverse is true is well known. A safety valve, opened so as to permit the escape of a thin film of steam, can be further lifted so as to permit the free escape of steam, only by considerable in-

crease of pressure, or by some special contrivance. It is usual to explain this phenomenon entirely by the increased resistance of springs due to increased

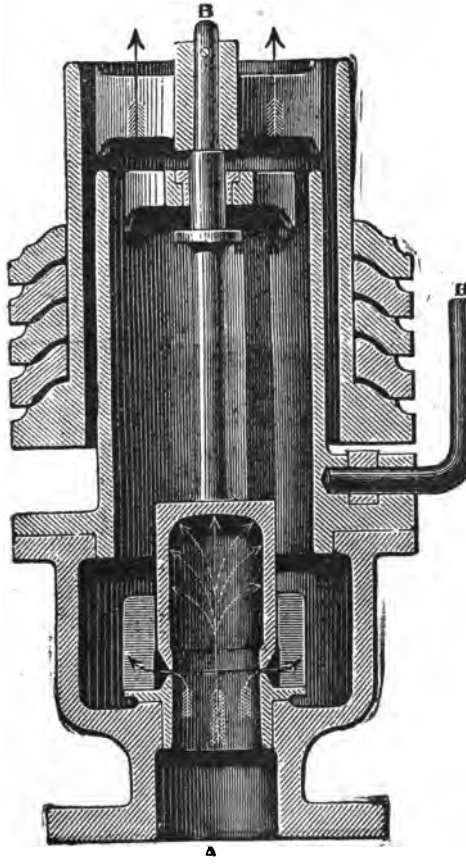


Fig. 25.—Dead-Load Open-Flow Valve.

tension; but this cannot be the sole cause, since the same thing is observed in a less degree where weights are used to close the valve. An additional cause is to be found in the expansion of a film of escaping

steam between the valve and its sit, as in the familiar "pneumatic paradox," described by Bourne as "the tendency which escaping steam has to shut the valve down." There is also a little sluggishness and hesitancy about a movement produced by a very slight preponderance of nearly balanced forces. All motion is attended with some friction and some inertia; and decided preponderance is required to produce decided movement. To counteract this inertness, and to give promptness and decision—in a word, to give "pop!" to the action of a safety valve, both in opening and in closing, many expedients have been invented.

REACTIONARY SAFETY VALVES.

The construction of reactionary safety valves is such that the steam, after passing the ground-sit of the valve, and prior to its final exit into the atmosphere, is opposed by a "stricture," so to speak, which stricture generally consists of an extension of the valve beyond the ground sit, and curved downwards; but in some instances is either straight or beveled, and a corresponding extension of the casing curved upwards.

One of the first in this line of improvement was an Englishman named Charles Ritchie, whose patent is dated March 2, 1848, and numbered 12,078. Ritchie's safety valve (Fig. 26) shows an annular lip, or flange, extending all around the valve, an annular chamber for escaping steam extending all around the valve sit, under the lip of the valve, and a "stricture," formed by a cylindrical ring rising from the outer border of the annular chamber, and encircling the lip, or "compensation flange," as its inventor calls it, so that steam, after passing in a thin film through the slightly-opened ground joint, is gathered, or "huddled," in the annular chamber, thereby soon acquiring the full existing pressure within the boiler, or nearly so; and, pressing upon the entire area within the outer border of the lip, overcomes the increasing resistance of the spring, lifts the valve so high that its lip surmounts the constricting ring,

and permits steam to escape all around a circle of larger periphery than that of the ground joint—the circumference, namely, of the constricting ring. When the desired relief has been obtained, and the pressure within the boiler has fallen by the amount provided for by the proportion of the lip to its valve, the spring closes the valve—slowly at first, and then promptly—giving the kind and degree of action to be desired.

The description of its operation, given in the speci-

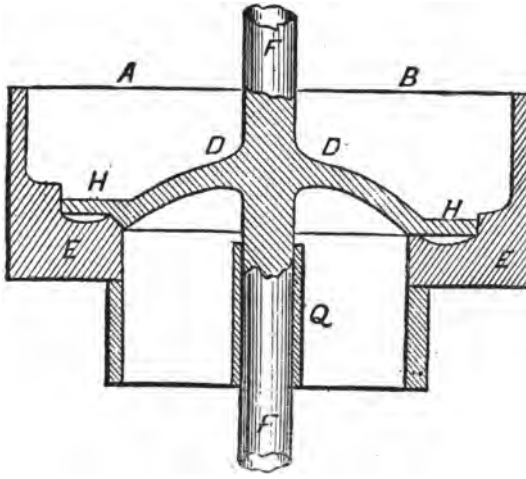


Fig. 26.—The Ritchie Valve.

fication, shows clearly a complete understanding of its principles on the part of the patentee. He says: "As soon as the pressure of the steam raises the valve from its sit, the flange H, being exposed to the pressure of the steam, presents an increased surface, which compensates for the increasing resistance of the helical spring (which surrounds spindle F, but not shown in cut), until the valve has been raised to a hight equal to the area of the steam way, when it allows the steam or vapor to escape freely."

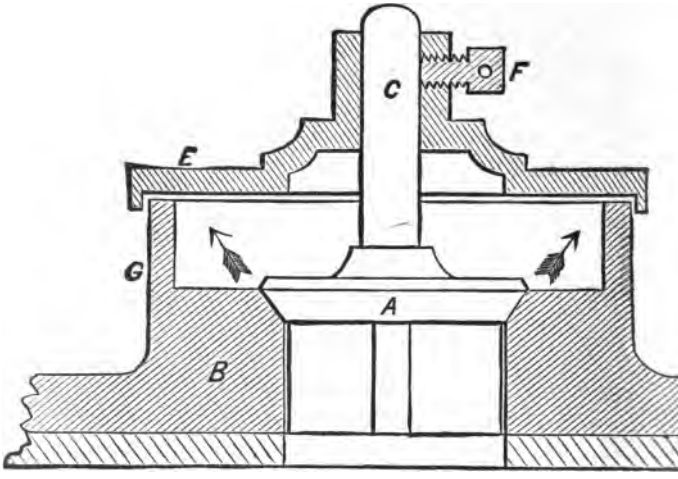


Fig. 27.—James Webster, July 14, 1857.

In 1857, James Webster was granted a patent in Great Britain (No. 1,955), for an improvement, or improvements, in safety valves. Several forms are

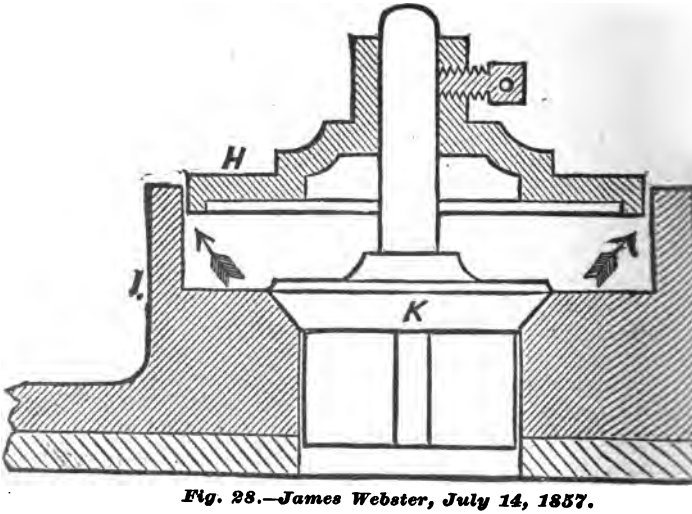


Fig. 28.—James Webster, July 14, 1857.

described in the specifications and shown in the drawings, some of them substantially identical with Ritchie's, and others equivalent thereto. In Webster's valve, the lip, or "compensating flange," instead of being formed in one piece of metal with the valve, is generally a separate and larger disk, attached to the valve stem above the valve; and the annular chamber, instead of being, as in Ritchie's, a mere

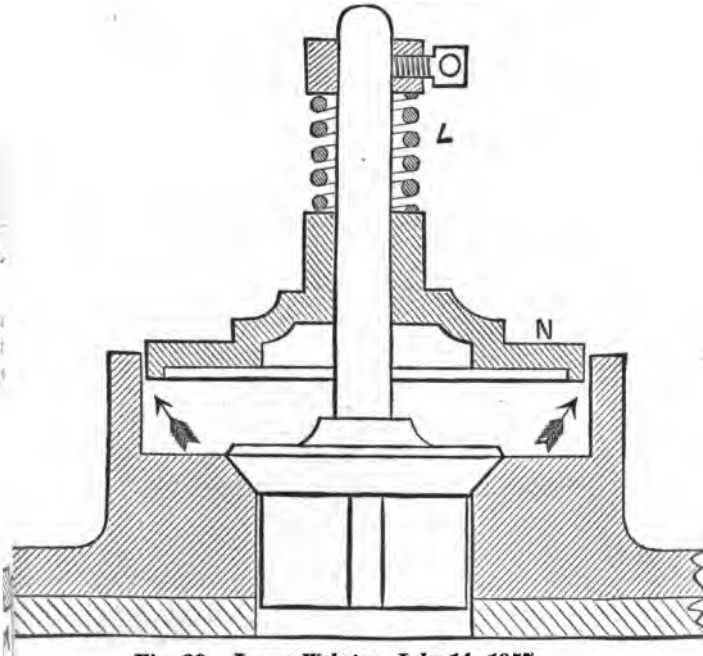


Fig. 39.—James Webster, July 14, 1857.

concave depression around the valve sit, is a considerable chamber around and above the valve, and between the valve and the disk. The "stricture" is formed by a cylindrical ring rising from the metal of the valve sit, at a little distance from the edge of the valve, and either embracing the rim of the disk, as shown in Fig. 26—exactly as in Ritchie's device —or itself encircled by a downward-turned rim on

the disk, resembling the cover of a snuff-box, a clearly equivalent device as shown in Fig. 27.

In another form, the superior disk, instead of being

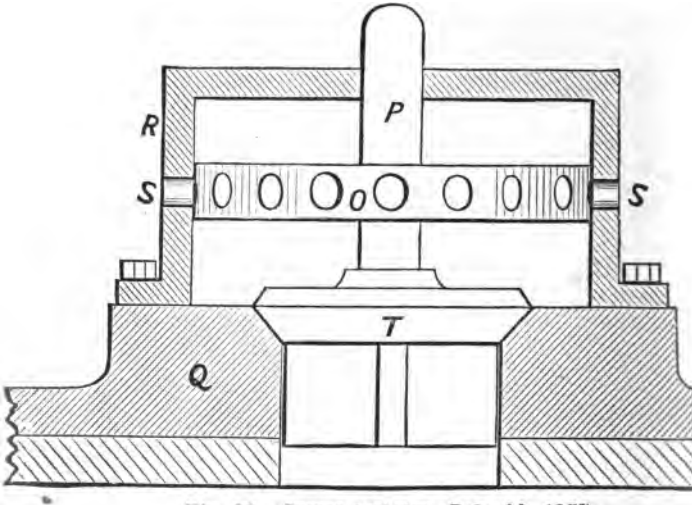


Fig. 30.—James Webster, July 14, 1857.

securely fastened to the valve stem, so as to act with the valve as if both valve and disk were one piece of metal, is connected therewith by means of a coiled

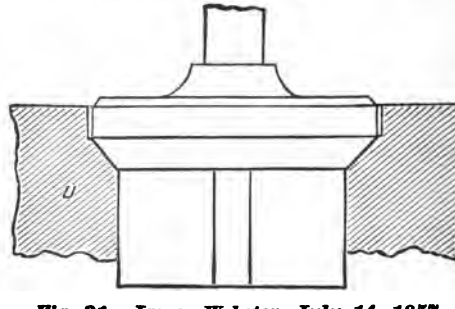


Fig. 31.—James Webster, July 14, 1857.

spring, which admits of relative motion between the valve and the disk, as shown in Figs. 29 and 30.

This is a new element, which has no resemblance to anything in Ritchie's patent.

In another form, the cylindrical envelope, or constricting ring, is closed at the top; the disk becomes a closely-fitting but freely-moving piston, and egress is given to the escaping steam by means of holes drilled through the walls of the encasing cylindrical ring, as shown in Fig. 30. There are corresponding holes in the rim of the piston, or disk, which come opposite the holes in the encasing cylinder when the valve is lifted to a desired hight.

In still another form, an ordinary safety valve, with conical sit, surmounted by a short cylindrical piston, rising from its outer edge, which fits closely but freely into a cylindrical envelope rising from the metal of the valve sit, as shown in Fig. 31. In the form Fig. 31 there is no "annular chamber," properly speaking—nothing to represent it except the space between the valve and its sit, so that there is, properly, no "stricture," and the action would be imperfect. In several of the other forms it is a good, practical safety valve.

William Hartley in the same year (1857), about a month later, patented improvements in steam engine and steam boiler apparatus. He describes his improvements in safety valves as follows:

"A safety valve for steam boilers is made to open so as to discharge a volume of steam equal to the discharge of an *unobstructed passage* through the valve sit. This I accomplish in two ways:

"*First.* By constructing a valve A, as shown in Fig. 32, with a projecting flange, on which is situated a curved, external rim B, projecting downwards, the section of the said valve and rim being similar to the section of an inverted cup, as shown in Fig. 32. When the valve is closed, the external rim is nearly in contact with the valve sit or its bearing; but when the valve is opened by the action of the steam, the distance of the rim from the valve sit, or its bearing, is equal to the area of the passage in the valve sit, thereby discharging its maximum quantity of steam.

"*Second.* I accomplish a full discharge of steam by making the projecting rim of a cylindrical form,

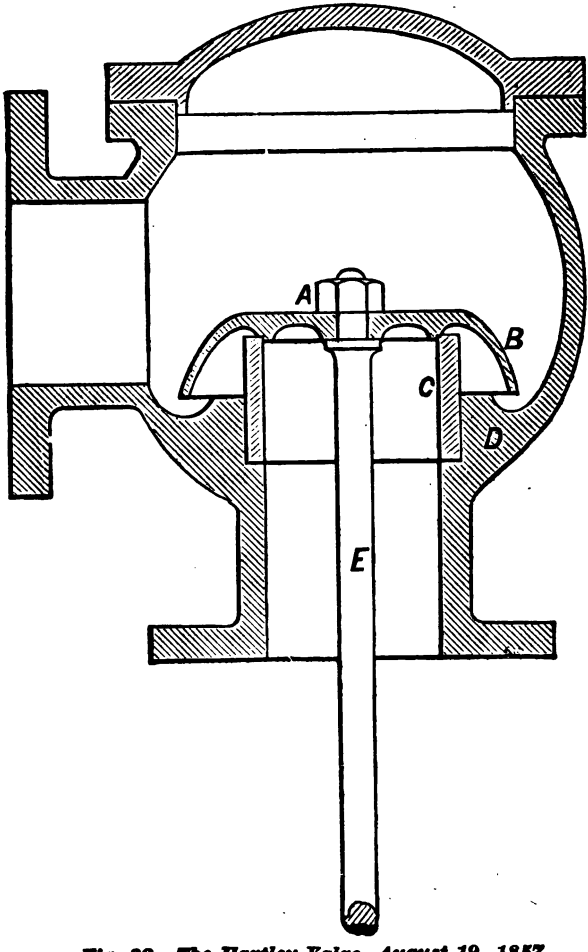


Fig. 32.—The Hartley Valve, August 19, 1857.

and the valve sit, or its bearing, curved, so as to increase in diameter downwards. In this case, when the valve A is closed, the bottom edge of the rim B

nearly touches the bottom part of the curved sit, or bearing, and when the steam lifts the valve, the space between the edge of the rim and the bearing increases

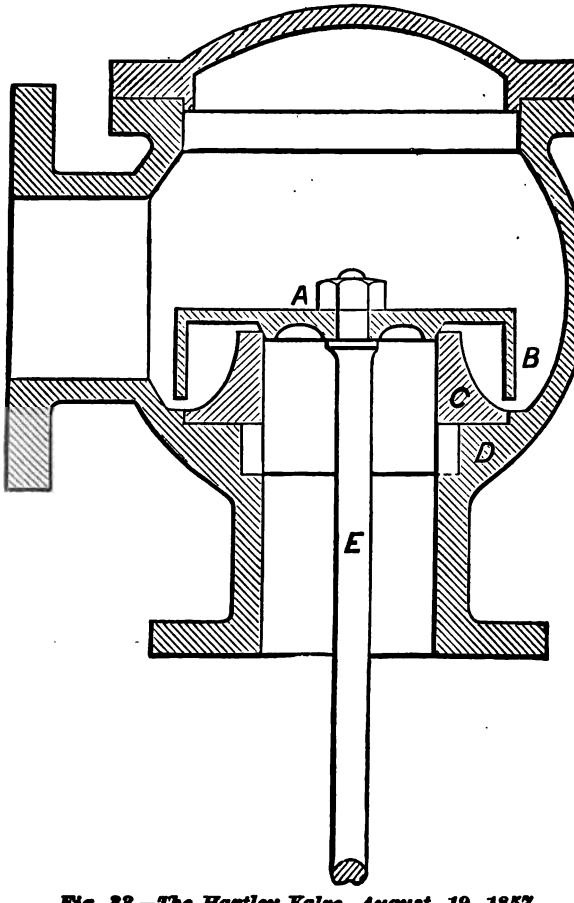


Fig. 33.—The Hartley Valve, August, 19, 1857.

in area, and thus effects a full discharge of steam. The rod E is weighted when placed below the valve, or loaded by a spring if above the valve. In both of

these arrangements the valve will close when the steam pressure becomes reduced below the load on the valve."

Charles Beyer also, in 1863, patented a valve similar to the above. He claims a flange around the valve, commencing at the outer edge of the valve-facing, which flange is under-cut, and concave in shape, and the concave side is towards the sit of the valve, which has also a flange upon it, commencing at the outer edge of the valve sit; but the upper surface of the flange is convex, and corresponds nearly to the concave surface of the flange upon the valve. There is a slight space between the concave and convex surfaces of the two flanges, which diminishes towards

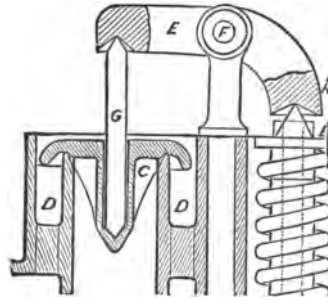


Fig. 34.—The Naylor Valve, July 21, 1863.

the outer edge of the flange. When the steam begins to escape from between the surfaces of the valve, it gets between the concave and convex surfaces of the two flanges, and its force thus acts upon a larger area, and reacts upon the concave surface of the valve and causes it to open to a greater extent than the ordinary safety valve.

In view of Ritchie (1848), Webster (1857), and Hartley (1857), there is in Beyer's device (1863) only a very narrow margin of novelty, if, indeed, there is anything beyond mere forms, wholly without effect upon the action of a safety valve.

In July, 1863, William Naylor patented and described a safety valve with a projecting, downward-

turned lip, similar to Beyer's, and to one form of Hartley's (Fig. 32), but lays no claim to its invention. He says: "By means of the curved, downward-projecting lip, I am enabled to avail myself of the recoil action of the steam against the valve for the purpose of facilitating the further lifting of such valve when once opened; but I wish it to be understood that I lay no claim to such recoil action, nor to the extension of the valve laterally beyond its sit."

Naylor's patent also contains two other devices: First, for compensating for the increasing resistance of the spring by the varying leverage of a bent lever, as shown in Fig. 34. Second, for a supplementary piston valve, for indicating the pressure existing in the boiler at all times, whether the safety valve is closed or open.

The bent-lever device is eminently practical, and affords one example of a way of making a "practical valve, working upon the principle of automatically relieving the boiler from excessive pressure, without a considerable enlargement of the steam passage to the atmosphere from the valve sit, followed by a comparatively quick contraction of this passage, which contraction is called a stricture.

Fair examples of reactionary safety valves in America are the Crosby and Richardson, which are well known and largely in use.

Fig. 35 represents the Richardson valve. In this valve a disk valve or cover sits upon the inner edge of a cylinder shell or body, having guides extending down into such shell or steam space, so far corresponding exactly to the ordinary safety valve in common use as before described. The end of the shell upon which the valve sits extends outwardly. The valve also extends outwardly from its sit, and downwards in the form of a lip, encircling the valve and relief outlet, and overlapping the extended shell, and is brought so nearly to such extended shell at its edge as to form a very narrow opening to the atmosphere. These extended parts form an annular chamber. A helical spring is used to close the valve against the pressure of steam within the shell or

body. The devices used to increase the lift of the valve, and give greater relief, are of such described parts as appear on the figure:

First. An annular lip C, outside and surrounding the valve B.

Second. The valve sit F.

Third. The relief outlet, shown by small arrows at lip C.

Fourth. An annular space or chamber D, formed by lip C and the extended shell E outside and surrounding the valve sit, the lip C overlapping the ex-

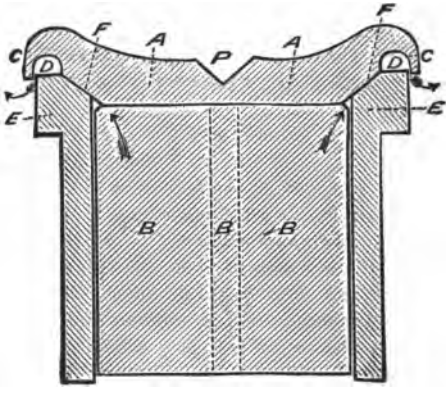


Fig. 35.—The Richardson Valve.

tended shell E slightly, and forming a very narrow annular opening from the chamber to the atmosphere when the valve is closed, but enlarging after the valve has lifted some distance from its sit.

Operation.—When the steam within the shell, or body, acting upon the whole face of the valve, is sufficient to overcome the resistance offered by the spring, the valve will lift and the steam escape from the relief outlet, under the valve, into the annular chamber, and there expanding, and finding but a very small opening to the atmosphere, acts, but with diminished pressure, upon the additional surface presented by the overhanging lip surrounding the relief outlet, and again exerting force to overcome

the resistance of the spring. The effect is, that the valve will lift higher, but the amount of steam passing the relief outlet under the valve is increased, before the annular opening at the outer edge of the lip is increased, owing to the over-lap, and the valve has to lift still higher and higher to give the necessary outlet to the steam entering the chamber from

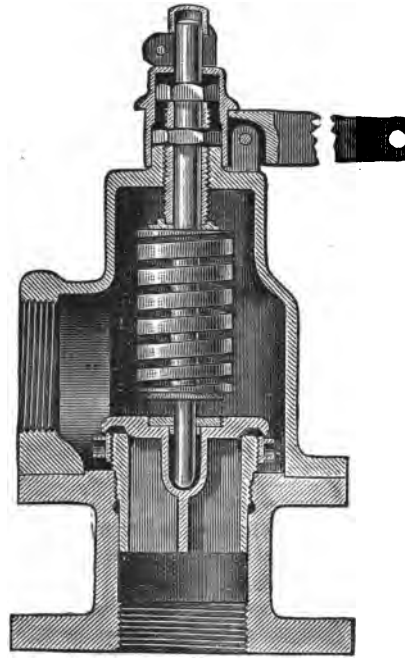


Fig. 36.—Lock-Up Safety Valve.

under the valve, until the extra force is counterbalanced by the increasing resistance of the spring.

The steam in the chamber, by being obstructed in its course to the atmosphere, by the lip, interferes with the free escape of the steam under the valve.

At the test at the Washington Navy Yard, one of these valves had two springs, so arranged as to exert

their strength and force in opposite directions—that is, the lower spring holds the valve down against its sit, and the upper one lifts it from its sit, so that the valve proper will open at a pressure equal to the difference between the adjusted power of the springs. For example: The lower spring is compressed sufficiently to hold the valve down at 100 pounds pressure, and the upper spring compressed to exert one-tenth of that force in an opposite direction; that is, to raise the valve. The valve will then lift at 100 less 10=90 pounds pressure.

Fig. 36 represents a lock-up safety valve, with means upon the outside to lift it from its sit. These

Fig. 37.—Solid Cast-Nickel Ring.

valves are made with either single or double springs, and without the lock-up arrangements. These valves also have an arrangement by which they can be retained in their sit whenever it becomes necessary to do so; such, for instance, as to apply the hydrostatic test to the boiler.

The excess obtained on these valves at 30 pounds pressure, was from ¼ to 7 pounds; at 70 pounds pressure, from 1¼ to 3¾ pounds. Areas exposed at 30 pounds, 0.869, 1.171, and 1.455 square inches; lifts, 0.15, 0.20 and 0.25 of an inch. At 70 pounds, 0.691 square inch; lift, 0.12 inch.

The records of the trial made upon these valves, show that the excesses above 30 and 70 pounds were varying, and that in some instances none at all were obtained.

The Richardson safety valves are made with a solid cast-nickel ring. Fig. 37 represents the solid

nickel casting used for the valve sit. The thread on the outside is for screwing into the base of the valve. It is threaded on the inside for the head of the valve, the contact is beveled at an angle of 45° to its center line of axis, and the metal, being so hard, enables

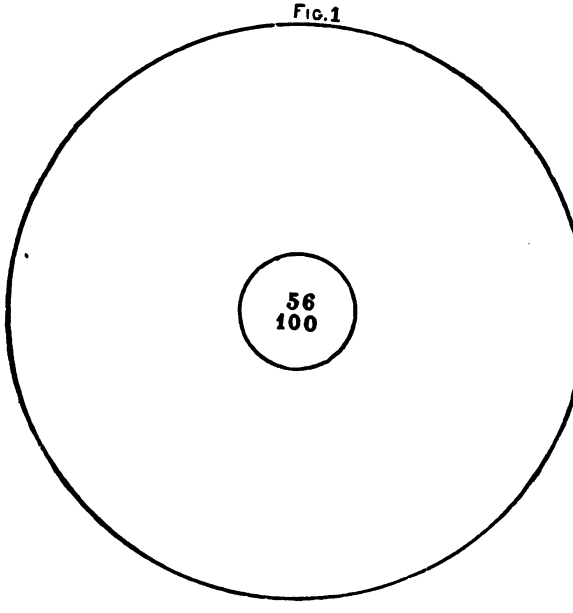


Fig. 38.—Three-Inch Common Safety Valve, and the Area of Opening Presented when the Valve Lifts for the Escape of the Steam.

the use of a very narrow-faced joint, or contact, with no danger of its cutting. Its chemical properites prevent corrosion from the action of water, steam, fatty acids of oils, or saline matter in the water.

All valves are fitted with an adjustable screw ring, so that the popping point can be changed while steam is in the boiler, without breaking any joints. These valves are absolutely reliable in their action, prompt in opening and closing at the proper moment, and

fully sufficient in capacity to relieve the boiler from any pressure in excess of the amount intended to be carried. Figs. 38 and 39 show the different areas of the ordinary and this valve.

The usual diameter of safety valves in use in the

FIG. 2

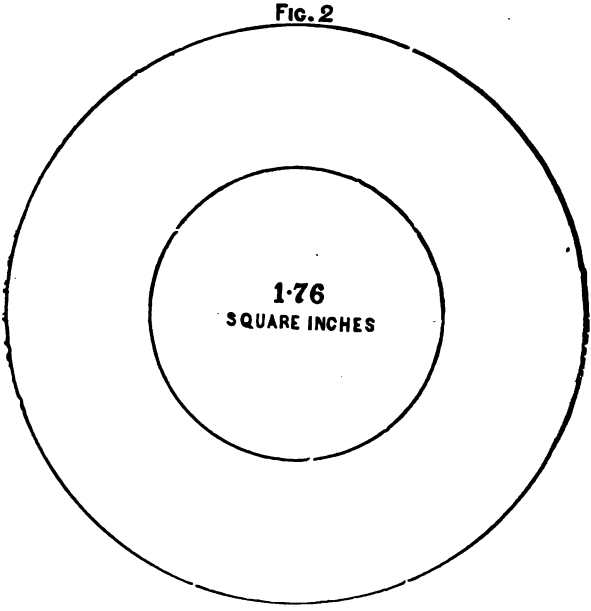


Fig. 39.—Shows the Nickel-Seated Safety Valve, and the Area for the Escape of the Steam when the Valve Lifts.

United States on locomotives, is 2¼ inches diameter, and each boiler is fitted in duplicate. Fig. 40 shows the spring F, which is the vital factor of spring-loaded safety valves. These springs are carefully selected, and the greatest care is used in the coiling, tempering and testing of the same. They are nickel-plated, to protect them from rusting.

The points of bearing, top and bottom, are ball and socket, preventing any tendency to tilt to one side and bind the spindle D, through which the press-

ure to hold the valve on its sit C is transmitted, and makes the valve thoroughly reliable.

The lip C′ is adjustable. If the valve reduces the pressure in the boiler too much, loosen the set-screw L, and turn the ring up a notch at a time; if it reduces the pressure too little, turn the ring down a notch at a time, until the desired pressure is reached,

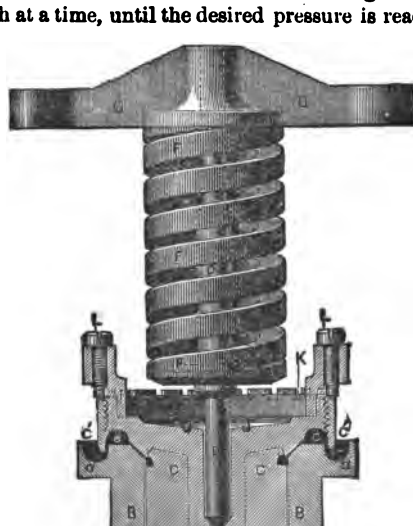


Fig. 40.—Richardson's Open Locomotive "Pop" Safety Valve, with Adjustable Screw Ring.

and then turn down the set-screws L L. The notch is shown at K.

THE CROSBY SAFETY VALVE.

The sits of this valve are flat, and it is claimed that the sits do not wear out or leak so readily as beveled sits, and *will never stick.* This valve is adjustable also; the point of opening can readily be changed while under steam, by screwing the threaded bolt L at the top of the cylinder up or down.

The Crosby valve has a compound or annulus-disk valve sit, at its periphery upon the edge of a cylindrical shell or body, and having guides projecting downward from the center of the valve into a

Fig. 41.—Crosby Locomotive "Pop" Safety Valve.

cylindrical chamber, situated under the center of the valve and inside of the space enclosed by the shell or body, and to which the steam has no access when the valve is closed. The boss, or chamber, is held

in its position by radial arms connected with the shell. The upper face of such boss, or chamber, is arranged to come in contact with, and protect, a certain portion of the face of the valve itself, from the

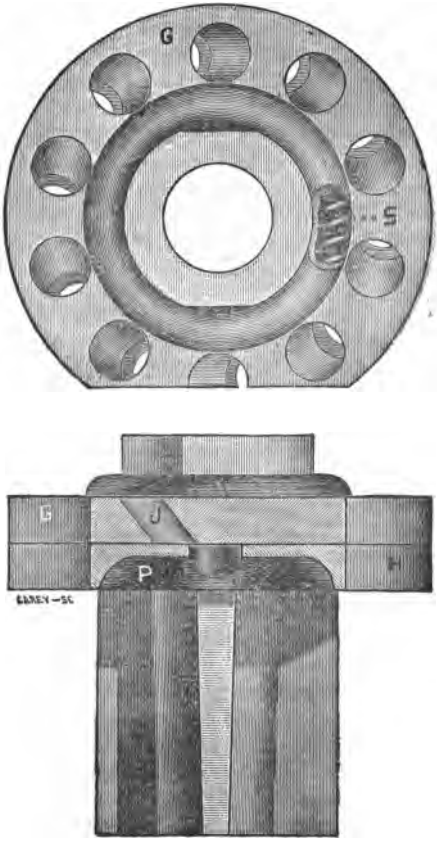


Fig. 49.—The American Pop Safety Valve.

action of the steam pressure, until the valve opens. Openings are made from this chamber, or boss, through the radial arms and shell, or body, to the atmosphere, and a ring or sleeve, is screw-threaded to the outside of the body to regulate the size of such

openings. A helical spring is used to close the valve against the steam pressure within the shell.

The devices used to give a greater lift to the valve, are such boss, or cylindrical chamber, C C, with its upper face W W, smaller than the valve B B, and, as has been described, and as appears from the cut annexed, so situated inside of the shell, or body, that its upper face shall come in contact with and protect a portion of the face of the valve itself from the action of the steam pressure within the shell, until the valve opens; and the small openings E E, from the boss, or chamber, through the radial arms and shell to the atmosphere. The size of these openings can be varied by the operator at will, but not by any action of the valve.

OPERATION.

When the steam within the shell, or body, acting upon that portion of the face of the valve not covered by the face of the boss, or chamber, is sufficient to overcome the resistance offered by the spring, the valve will lift, and the steam will escape from the relief outlet, under the valve at its periphery, into the atmosphere unobstructed, and no further use is made of it. At the same time that portion of the face of the valve itself which was protected by the boss, or cylindrical chamber, from the action of the steam pressure is uncovered, and the steam acts upon such surface with great power also, and exerts a force to overcome the resistance of the spring. In lieu of changing this central area for every change of pressure required, the pressure acting upon the fixed central area of the portion of the face of the valve so uncovered, is reduced to the proper amount by the size of the openings from the boss, or chamber at their outlet.

The effect is, that the valve will lift higher, and the relief outlet is enlarged to any degree desired without the slightest obstruction to the free escape of the steam under the valve into the atmosphere.

The navy-yard trials showed that the excess obtained on this valve at 30 pounds pressure was from

2¼ to 5¼ pounds; at 70 pounds pressure, from 3 to 5 pounds.

Areas exposed at 30 pounds, 1.257 square inches; lift, 0.13 inch; at 70 pounds, 0.729 square inch; lift, 0.07 inch.

These excesses were only temporary, and upon trial after readjustment, no excess was obtained, but the range of pressure between the opening and closing points was about the same on all the trials; that is, if the valve made less excess, or none at all, it seated at a lower pressure.

THE AMERICAN POP SAFETY VALVE.

This safety valve is provided with a second or movable head on the top of the valve proper, as shown in Fig. 42:

MOVEMENT.

H—Valve.

J—Inclined holes in automatic head G.

G—Adjustable automatic head on top of valve H.

S—Spring to return the head to its position after the valve has stopped blowing.

P—Cavity for the accumulation of steam to feed holes through valve H, and head G.

There are two series of holes drilled around the outer edge of these heads, for the purpose of reducing the amount of increased area.

First. The first series is drilled around the head of the valve proper and drilled at an angle of 90°, and the sit of the same.

Second. The series is around the second or movable head G, and drilled at an angle of 55° with the holes in the head of the valve H.

Now, the movable head is placed in such a position upon the head of the valve H, that there is a small opening between the holes in the head of the valve H, and in the corresponding holes in the second or movable head G.

It will readily be seen that the result of this device is simply this, that when the valve lifts from the sit to blow, the passage of the steam through the holes in the head of the valve H passes into the correspond-

ing holes in the movable head G; and, as the walls of the holes in the head G are at an angle of 55° with the holes in the head of the valve H, the automatic head G will be forced around in such a manner that

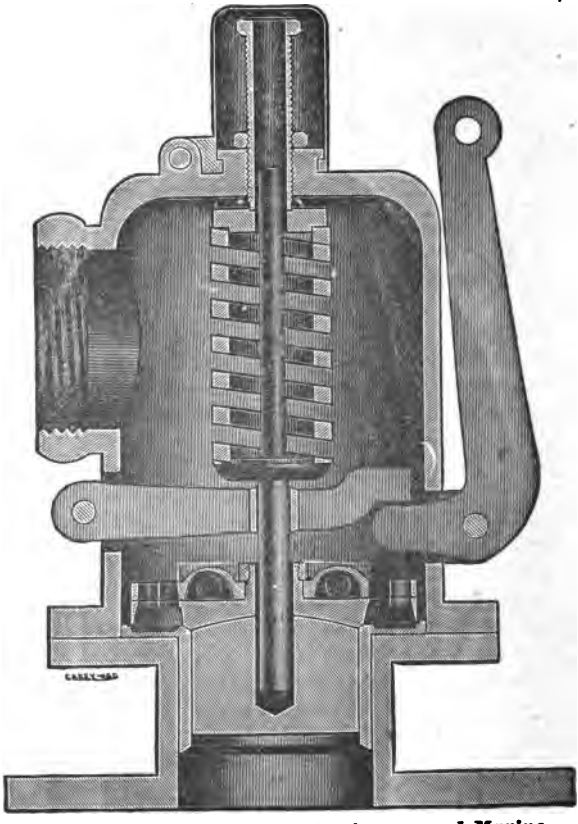


Fig. 43.—Safety Valve for Stationary and Marine Boilers—Interior View.

the holes of the two heads will be directly in line with each other, the result being a decrease of increased area.

Fig. 43 shows a section of the inside of a safety valve.

The United States Board of Supervising Inspectors of Steam Vessels, require for *lever* safety valves, one square inch valve area for every two square feet of grate surface of boiler. For *spring-loaded* pop

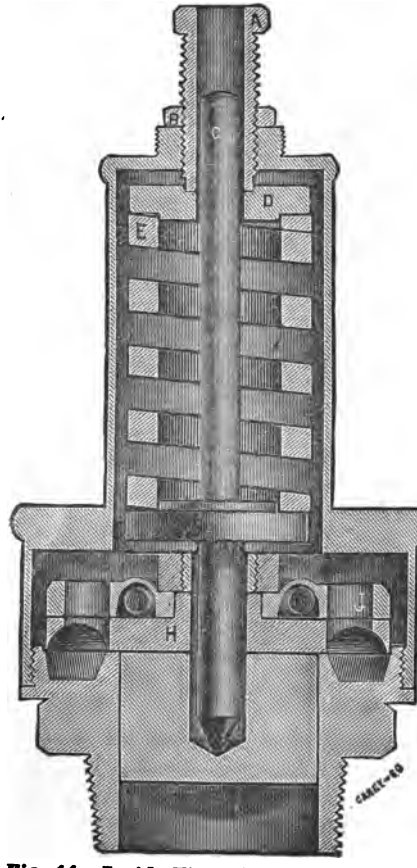


Fig. 44.—Inside View of Locomotive Valve.

valves, one square inch valve area for every three square feet of grate surface in the boiler.

LOCOMOTIVE POP SAFETY VALVE.

When the pressure in the boiler reaches the pre-

dominated point at which the valve H is set to blow, the valve will rise slightly from its seat, and allow the steam to escape into the expansion chamber under and around the valve; and, as soon as the escaping steam into this chamber has created a slight pressure above the atmosphere, the valve H will at once be forced upward to its extreme lift, when at that point, The steam passing through the inclined holes J will force off the automatic head G, causing a reduction

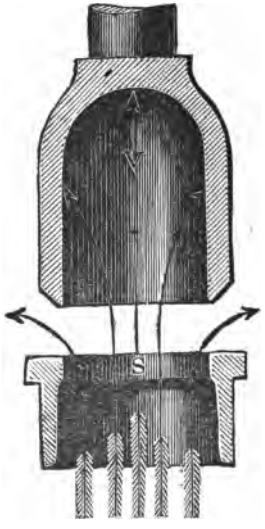


Fig. 45.

of the increased area, and a rotation of the valve until it again reaches its sit, when the automatic head will be forced back into position by its spring E, and the valve is ready for the next operation.

A—Screw to adjust spring to pressure required.
B—Check-nut to hold screw after being adjusted.
C—Spindle.
D—Follower for spring.
E—Spring.
F—Nut to hold adjustable head.

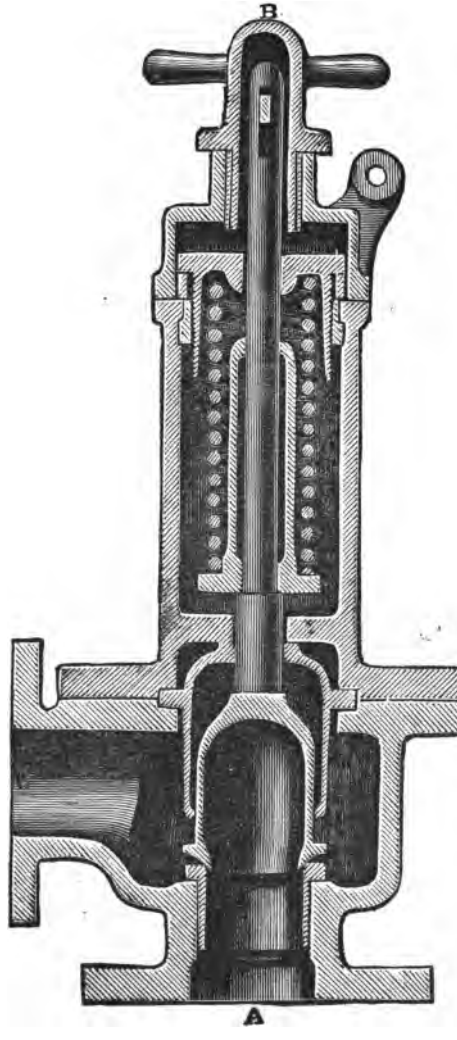


Fig. 46.—Turnbull's Lock-Up, Spring-Loaded Valve.

G—Adjustable or automatic head.
H—Valve.
J—Inclined holes in head.

The makers claim it the safest, most reliable, and *only* automatic adjusting pop safety-valve, and that its action is such that it will *never stick* on its sit.

TURNBULL'S EQUILIBRIUM SAFETY VALVE (GLASGOW, SCOTLAND).

The inventor of this valve claims that it will lift with the slightest increase of pressure, and will close practically at the identical pressure at which it opens. The chief features in these valves are that they are entirely free from all obstructions, such as guides, feathers, etc., in the steam passages to which they are fitted, while the valves themselves are of bell form, as shown in Fig. 45; the arrows indicate that it is supported somewhat on the principle of the hydrostatic paradox.

The valve consists of an inverted cylinder, or bell, chamfered at its lower end, and resting on a flat surface of small extent (see Fig. 46).

For marine or stationary purposes, the form of the valve is as above described, but the valve is guided externally at the lower end by a brass cylindrical casing, as shown in Fig. 46, this guide having only a narrow surface in contact with the valve. The arrangement of the spring will be readily understood from Fig. 46, and it will be seen that the upper end of the valve spindle is guided by an extension of the spring compression nut.

DISK SAFETY VALVES.

Through the use of the disk the same object is sought to be obtained as by means of the reactionary principle. The disk is usually located below the ground sit of the valve, between which and the disk there is a space which may be designated as a reduction chamber, for the reason that when the valve proper is forced from its sit by the pressure in the boiler, the pressure in this chamber is reduced, thereby allowing a greater force to act against the lower and

inner faces of the disk (which is of a greater area than that of the valve proper) than that acting between the valve proper and the disk, forcing the valve further from its sit.

In valves constructed with disks attached to their spindles, either below or above their ground sit, the disks are of larger areas, than the areas of the valve proper, and when attached to the spindles be-

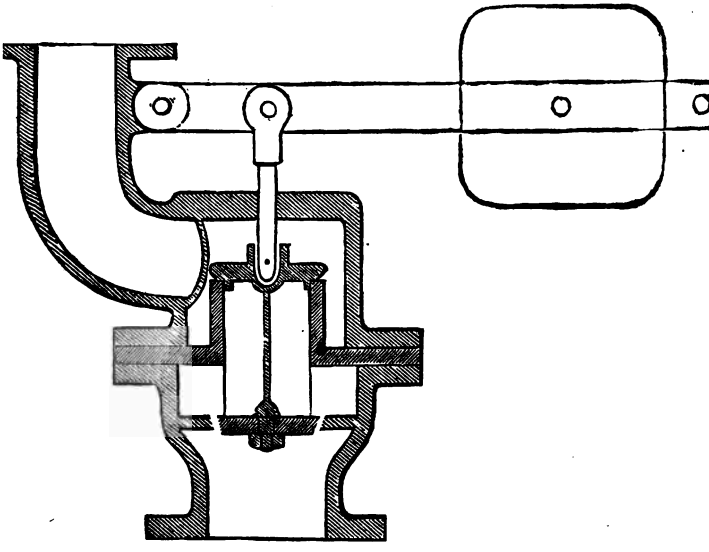


Fig. 47.—Dead-Loaded Disk Safety Valve.

low the ground sits, operate in a recess, which may be termed a "reduction chamber."

The Cockbourne is a fair example of this form of safety valve.

COCKBOURNE DISK SAFETY VALVE.

Fig. 47 shows a section of this valve with a stationary weight, those spring-loaded being the same.

The valve proper is constructed in the usual manner, with feather-edged wings, or guides, extending into the casing. These guides extend some distance

below the point where they come into contact with the casing, for the purpose of receiving and sustaining the disk, the disk being considerably larger in area than that of the valve, and nearly filling the lower

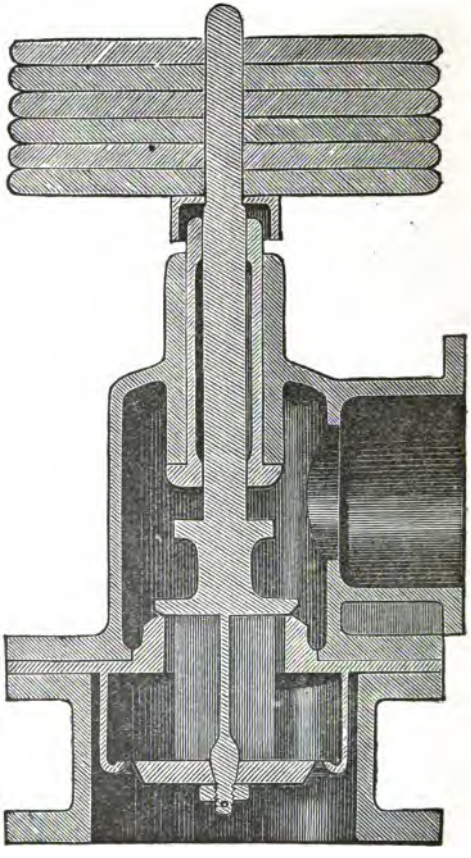


Fig. 48.

opening in the casing. The edge of this disk is beveled. Below the casing, carrying the sit of the valve, and above the disk, is a chamber of considerable area in extent, as shown in Fig. 48.

The result of this arrangement is, that the steam, in its passage through the narrow space between the disk and the casing below the valve, becomes wire-drawn, thereby diminishing the pressure in the chamber, upon the upper side of the disk. Consequently the under side of the disk, being exposed to the greater pressure in the boiler, is forced upwards, and a greater lift is thereby given to the valve than that due to the pressure and volume of steam in the boiler. The thickness of the edge of this disk, as well as its form, has much to do with the action of the valve.

These safety valves at the Washington navy yard trials showed no excess at 30 and 35 pounds pressure. Lift, 0.23 inch; area, 1.82 square inches. The valve tested at 35 pounds was spring-loaded. The excess obtained at 70 pounds pressure, was one-quarter of a pound. Lift, 0.15 inch; area, 1.18 square inches. This valve was loaded by a lever and weight.

REACTIONARY VALVES.

As the reactionary valves, such as the Adams, Turnbull, and others, of England; the Richardson, Crosby, American, and others, of America, constitute a type which has come into very general favor, and have just been described and illustrated, the construction of these valves is now widely known, and a brief *résumé* will suffice. The outer edge of the valve is extended to form an overhanging lip, and the simple explanation of its action, is, that the steam, in rushing out in the direction of an angle of say 45°, is deflected by the overhanging lip, an upward pressure tending to force the valve further from its sit, is produced, and thereby obtain a larger area than that primarily due to the pressure and volume of the escaping steam when acting only upon the area due to the diameter of the valve proper.

It is quite evident, however, that if the steam, after passing the ground-sit of a safety valve, and before it can make its final exit into the atmosphere, is opposed by any means which will act to retard its escape, and force it against the valve sit, and any

overhanging portion of the valve, will have a tendency to force the valve further from its sit than it would if left free.

It is a fact, that such valves must expose a larger area than valves where the steam passes unobstructed by such means direct from their ground sits to the atmosphere, in order to discharge the same volume of steam.

In the report of safety-valve tests made at the United States navy yard, Washington, D. C., by a special committee of the Board of Supervising Inspectors of Steam Vessels, September, 1875, is the following:

"Some of these reactionary valves proved very efficient, but the committee are not quite sure that they will prove to be the best in a long run. It appears to the committee that the nicety of the adjustments of parts required by the sharp lines of the stricture, as well as the fact that no one valve can be adjusted to more than one pressure, at least within a very narrow limit of pressure, without extra springs, will cause them more frequently to get out of order than the common lever valve, or some of the disk valves. The action of this construction of safety valve under pressure, may be described, in general terms, as *erratic, tremulous*, and, in some instances, *tumultuous*. It was very difficult to adjust some of these valves twice alike, or to make them constant in their action, and they would not always give the same result under the same adjustment."

COMMON LEVER SAFETY VALVE.

The committee say, in regard to the trial of the common lever safety valve (see Fig. 22, page 109, May number, 1889, as follows:

"*First.* That the diameter of a safety valve is not an infallible test of its efficiency.

"*Second.* That the lift which can be obtained on a safety valve, other conditions being equal, is a test of its efficiency.

"*Third.* That the lift of a safety valve depends upon the velocity and weight of the escaping steam.

"*Fourth.* That the valves with small areas made a greater excess than those with large areas, even when the former recorded a greater maximum of effective area.

"*Fifth.* That two-tenths (0.2) of one inch is the maximum lift to be obtained on a common lever safety valve.

"*Sixth.* That the common lever safety valve, when constructed upon correct principles, employing good material and workmanship, will correctly indicate the maximum pressure of steam in a boiler, and, when suitably proportioned, relieve the same of all excess."

They further say, that "in the arrangement of safety valves for any boiler, or set of boilers, the committee is of the opinion that a number of valves (where more than one is required) is preferable to one valve with a large area; and do not believe it advisable to employ a common lever valve, with either a beveled or flat sit, of more than 10 square inches area. According to these experiments, two such valves will discharge *four thousand* pounds of steam in one hour, at all pressures from 20 to 100 pounds per square inch: and if the results deduced from the experiments are taken as conclusive, the rule of proportion is all that is required in arranging the areas necessary to discharge the weights of steam generated, without any reference to its pressure."

The following rule is the nearest approximation these tests will warrant:

Weight of water evaporated in one hour, multiplied by 0.005; or,

An area of 5 square inches, up to 1,000 pounds evaporated per hour.

An area of 10 square inches, from 1,000 to 2,000 pounds.

An area of 20 square inches, from 2,000 to 4,000 pounds.

An area of 30 square inches, from 4,000 to 6,000 pounds.

An area of 40 square inches, from 6,000 to 8,000 pounds.

ANNULAR SAFETY VALVES.

These valves are constructed with two ground sits upon an annular opening, and allowed an external and internal escape for the steam. Some annular valves have attached to the valve or casing an adjustable lip, for the purpose of controlling the exit of the steam. The object sought in the construction of this safety valve is *an increase of area.*

One form of annular valve is shown in Fig. 49, the external diameter being 4 inches; internal diam-

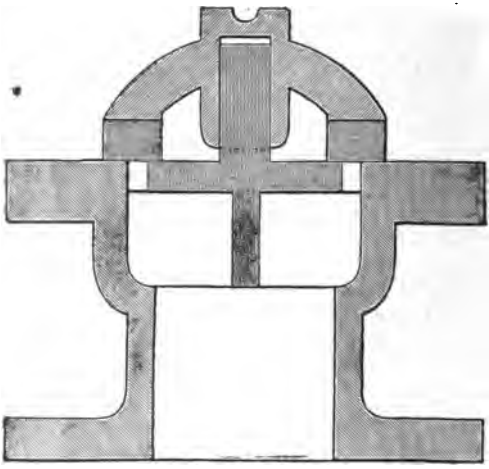


Fig. 49.—Annular Safety Valve.

eter, 3.25 inches. The steam passes outside of, and through, the valve to the atmosphere.

The valve shown in Fig. 50 has proved a very efficient safety valve. Steam is discharged at the outer edge of the valve, and through apertures in the valve itself. The valve is guided to its sit by means of a central spindle extending below its sit. The principle of annular safety valves is not new.

DOUBLE-SIT SAFETY VALVES.

These valves are constructed with two openings of unequal areas for the escape of the steam. The valves

are attached to the same spindle, and the pressure, acting upon the one with the larger area, tends to force it *from* its sit; the pressure acting upon the one with the small area, tends to force it *to* its sit. The extra force applied to prevent the valve from opening is just sufficient to balance the difference between the two areas.

The inventor of this safety valve claims simplicity

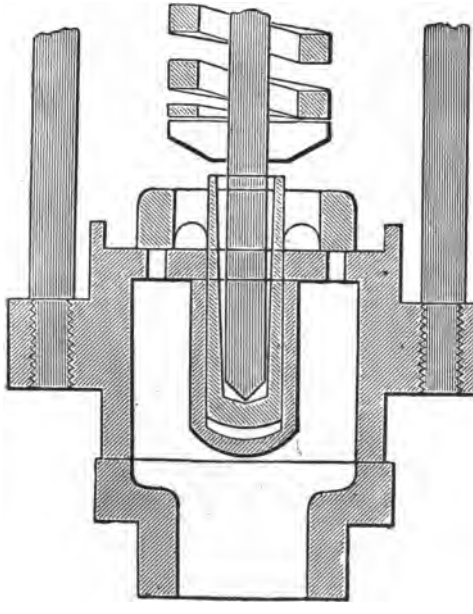


Fig. 50.—Annular Safety Valve.

of arrangement of parts; that it will relieve a boiler of all excess of pressure quicker and more freely than any other safety valve; that it will raise exactly at the pressure desired, and re-seat instantly on the pressure receding below the point at which it opens; and that it is not liable to be acted upon by rust and dirt from a boiler.

The *ratio* of the difference between the areas of the two openings is so arranged, that, by the addi-

tion of one pound weight to the valve stem, one pound additional pressure per square inch will be necessary to open it.

On a test made of this valve, the claims of the inventor were not sustained. It is doubtful if *double-seated valves* will ever be made to answer the purpose intended.

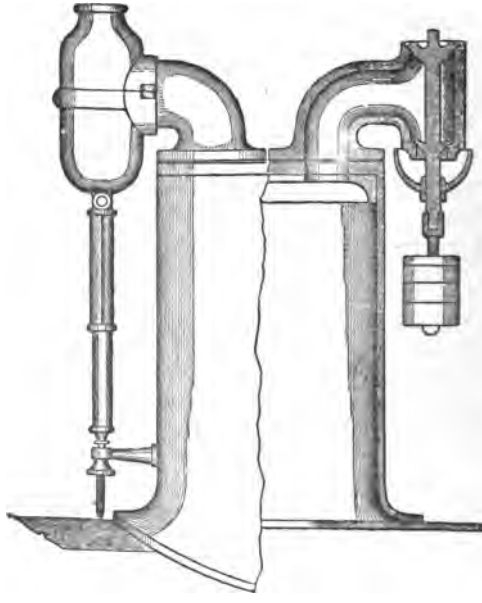


Fig. 51.—Double-Sit Safety Valve.

PISTON SAFETY VALVES.

Piston valves are operated by the pressure of the steam acting against the end of a piston fitted to a cylinder, forcing it outwards, and uncovering gradually the opening of the valve.

The one great objection to the use of piston valves, namely, that they are likely to become clogged by the accretion of matter around them (unless in constant operation), as to prevent them from operating until a large excess of pressure is attained, militates against

their general use. There is no doubt that in this form of valve a much larger effective area can be obtained than with the common lever valve, and one with a smaller diameter may be employed.

The piston of the valve shown in Fig. 52 is of a larger area than that of the valve proper, and is located some distance below the valve sit, and attached to the valve by means of a spindle extending downwards. Between the piston and the valve proper is a space

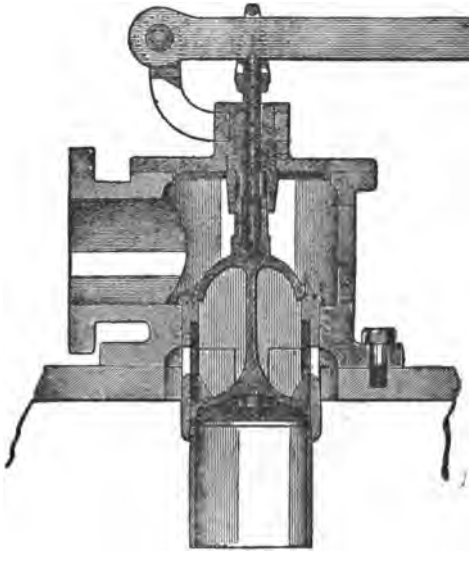


Fig. 52.—Piston Safety Valve.

which may be called a reduction chamber. The steam is admitted into this chamber through apertures in the surrounding casing just above the top of the piston, and when the pressure exceeds the resistance of the weight on the valve proper, and lifts it from its sit, it brings up with it this piston. The apertures in the casing are, by this action of the valve, partially closed by the piston, and the steam is gradually being cut off, thereby reducing the pressure in the reduction chamber, and upon the upper side of the

piston. This reduced resistance to the rising of the piston, and the area exposed to the pressure of the

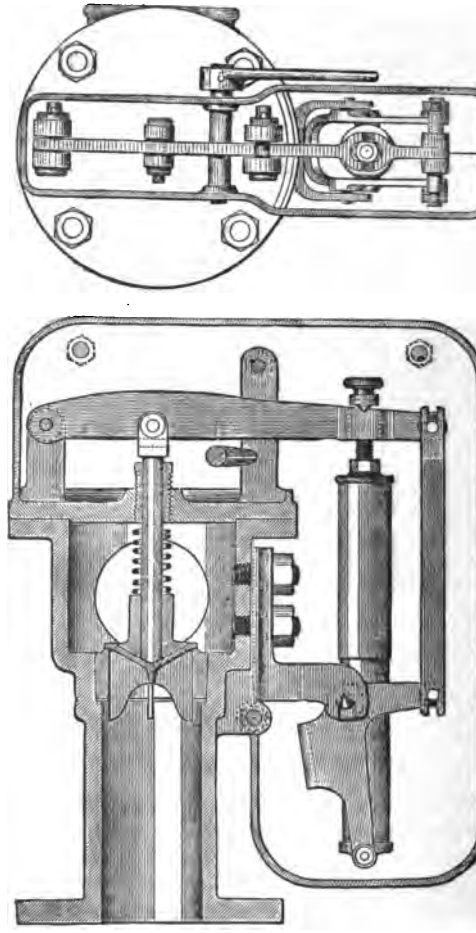


Fig. 53.—Spring and Lever Loaded Bell-Crank Combination Safety Valve.

steam in the boiler being somewhat in excess of that of the valve proper, it forces the valve further

from its seat, where it will remain until the pressure in the boiler is sufficiently reduced to allow the piston to fall below the apertures above mentioned, when the valve proper will suddenly seat itself.

COMBINATION SAFETY VALVES.

The great objection to combination safety valves, is that they are too complicated. The object in this form of valve is to obtain an effective area equal to that due to the diameter of the opening of the valve —a worthy effort. The writer entertains hope that inventors will not despair of success, but will continue their efforts to reach such a result.

In Fig. 53, it will be seen that from the end of the lever, extending downwards, is a bar which connects with the short end of a toggle, or bell-crank lever, to the long end of which the spring-balance is attached, and in the position to act upon the main lever through the connecting-bar above mentioned whenever the pressure in the boiler overcomes the resistance of the spring-balance, and assists in raising the valve from its sit. The object of this arrangement is to get an increase of lift to the valve.

DUAL SAFETY VALVES.

By the city ordinance for the inspection of boilers in the city of Philadelphia, in accordance with Acts of Assembly approved May 7th, 1864, also ordinance of Councils, approved July 13th, 1868. all steam boilers are required to have on each boiler, when fired separately, two or more safety valves. When a given safety valve area is distributed over two or more valves, the efficiency for the relief of steam is greater than when the area is contained in one valve, because the circumference of the valve of a safety valve is the measure of the amount of orifice that is presented for the outflow of the steam; for example, an area of 20.62 inches is required, and we find that two valves, each 3¾ inches in diameter, equal the above, and their circumference amounts to 22.76 inches; but if we have only one valve, its diameter would be 5¼ inches, and its circumference 16.10 inches. This comparison shows the advantage and

wisdom due to two safety valves in point of safety, regardless of its advantage of less risk of both valves being out of order at the same time.

RAMSBOTTOM'S SAFETY VALVES.

Ramsbottom's arrangement consists of two safety valves held down by a single stout helical spring, placed midway between them. The spring holds down both valves with equal force, and the cross-bar to which the spring is attached, and which rests upon both valves, is prolonged at one end, so as to afford a handle by which the engineer may occa-

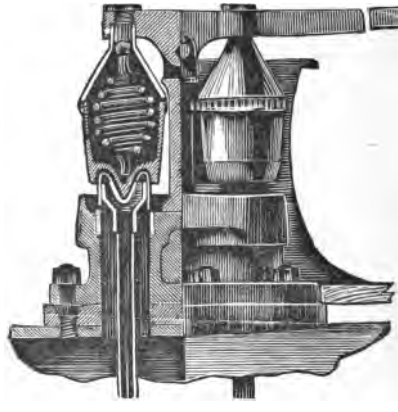


Fig. 54.—Dual Safety Valve.

sionally try his steam. Any movement of this handle by the engineer, whether up or down, frees one valve in pressing down the other; and it is thus impossible, by holding down or fastening down this handle to prevent the escape of steam, and thus increase the pressure: for to force down, or to force up, the handle would only let off steam, This feature the writer believes is one of the best yet introduced for safety valves. When the pressure rises too high, both valves blow off alike, and both rise to the full extent to which the spring is extended, instead of, as in the ordinary arrangement, to but one-eight, or perhaps one-twelfth, of the extension

of the spring. Even with a strong fire, the steam cannot rise but a very few pounds above the pressure at which the valves are set to blow off.

In this safety valve the pressure can be removed from either valve at pleasure, by merely raising or depressing the free end of the lever, while at the same time the arrangement prevents over-loading.

AN IDEAL SAFETY VALVE.

The theoretical action of an ideal safety valve would be to prevent the slightest accumulation of pressure above the amount intended, and not to contribute to the falling of the pressure below that amount; that is to say, the moment the normal pressure began to be exceeded, the valve would rise to admit the escape of steam, and would rise to just the extent necessary to allow the proper quantity of steam to escape, and the moment the tendency to undue accumulation ceased, the valve would close; and at all intermediate stages of time between its first opening and its closing, the amount of opening would be exactly proportioned to the surplus steam formed. Practically, we know it is impossible to construct such a valve, the first difficulty we encounter being the friction of the valve and its holding-down apparatus, which prevent the valve rising until some slight accumulation of pressure has taken place, and which prevents its closing until the pressure has fallen somewhat below the normal point. In practice, a valve never presents at its first opening sufficient orifice for the escape of all the surplus steam the boiler can generate, but it is only after the pressure has risen somewhat above the point necessary to open the valve, that the orifice becomes sufficiently large. The cause of this is generally understood to be that the further the valve rises from its sit the greater is the decrease of pressure due to the issue of the steam compared with the pressure inside the boiler, therefore the greater the hight to which it is necessary to raise the valve the greater the surplus pressure in the boiler must be to raise it, and thus, to give sufficient area for

the discharge of all the steam a boiler can generate, the pressure must rise in the boiler above the intended limit — that is, above the point at which the valves are arranged to begin to blow off.

THE FIRST EXPLOSION BY AN OVER-WEIGHTED SAFETY VALVE.

Dr. S. Gravesande, secretary of the Dutch embassy, who were in England in 1716, saw Captain Savery's pumping engine, and afterwards had one erected for a friend. He gives the following description of the boiler exploding—the first on record:

"The boiler was made spherical. Upon the safety valve there was a steelyard, the place of whose weight shows the strength of the steam, and how high it was capable of raising water (24 feet high). But when the weight was at the very end of the steelyard, the steam then being very strong, would lift it up, and go out at the valve rather than damage the boiler. But a man who was entirely ignorant of the nature of the boiler, without any instructions, undertook to run it, and, having hung the weight at the further end of the steelyard, in order to collect more steam to make his work quicker, hung also a very heavy plumber's iron upon the end of the steelyard. The consequence proved fatal, for, after some time, the steam, not being able, with the safety clack, to raise up the steelyard, loaded with all this unusual weight, burst the boiler with a great explosion, and killed the poor man in attendance, by the pieces that flew asunder, there being otherwise no danger, by reason of the safety valve being made to lift up and open upon occasion."

VACUUM VALVES.

A vacuum valve is a safety valve, opening inwards, for admitting air and preventing collapse in the shell when the pressure in the boiler is much less than that of the atmosphere. Falling of pressure in the boiler may arise from condensation of steam by gradual cooling after the fires are withdrawn.

THE DEVIL RAN AWAY WITH THE SOUP.

The advantage of having vacuum valves on steam boilers and steam supply pipes, is best illustrated by

W. F. Durfee's description of how the devil ran away with the soup from the kitchen at the old City Hospital, which formerly stood for many years on the west side of Broadway opposite Pearl street and between Duane and Anthony streets, New York city.

Mr. Durfee says: "About the year 1850, I accompanied my father to New York, his purpose being to visit some of the public institutions with a view of studying the various methods then in use for cooking and heating by steam, and among other places of note we went to the above-named hospital, whose superintendent very courteously showed us through the building and explained the system used for heating, ventilating and cooking. When we came to the kitchen, we found three (I distinctly remember that they seemed to me enormous) large iron caldrons grouped together in the center of the room. These were provided with wooden covers having hinged lids, and we were told that they were used to boil the soup and meats by blowing steam directly into them through a pipe which entered the center of their bottom. On my father inquiring if that method was found to be satisfactory, the superintendent replied: 'Yes; except in one instance.' He then told us that one day the chief cook (who was a Frenchman) came rushing into his office with every hair on end, and his face livid with fright, exclaiming: 'Monsieur! sacré Moïse! ze diable avez rund avay mit mon soup. Zer es not un piece of ze soup; ze diable avez him entierement. Ah! Monsieur, wit me come, vouz sal see wiz vous eye. I say ze vérité. Parbleu! Monsieur, et es ze grand satan!' I supposed, said the superintendent, that my cook was either insane or drunk, but I accompanied him to the kitchen, and on lifting the lids of those kettles, there was not one drop of soup to be seen, and only a few grains of rice to show that there had been any there. Voilla! vous zee vat I tell'd vous; ze diable il a ze soup! Sacré Moïse, vat sal ve do?' exclaimed the cook, and I began to think that his theory had appearances to justify it, if nothing more, and I certainly

had no explanation of my own ready for the occasion. However, investigation was in order, and its result showed that the cook was not far from right, for we very promptly discovered that the fireman was dead drunk, and, of course, had allowed the fire under the steam boilers in the cellar to go out, and as the boilers cooled, a vacuum was formed in the place of the steam, due to its condensation by the cold air surrounding the steam pipes and the top of the boiler, and as a consequence all the soup intended for that day's dinner had been drawn into the steam space of the boiler to satisfy its hunger; so the incarnate devil of drunkenness, in the person of the fireman, had deprived the establishment of a very important part of that day's dinner."

The lesson taught by this experience, is to be sure and put vacuum valves on boilers and check valves on steam pipes, when used under similar conditions. Probably the colloquialism, "In the soup," may have had its origin in the kitchen of the New York City Hospital forty years ago.

ATMOSPHERIC PRESSURE ON SAFETY-VALVE DISK.

The effect of atmospheric pressure on a disk can best be illustrated by the following simple experiment: If any one will take a piece of writing-paper about one inch in diameter, and place it on the open part of the head of a common tobacco-pipe, and insert in the paper three small pins as guides, he will find it utterly impossible to blow the paper disk off the pipe by blowing down the stem. By reversing the pipe while blowing, the paper will not fall off, but in this position, the moment one leaves off blowing it will drop. A disk of metal may be suspended in the same manner.

This phenomenon in steam was first observed by Clement Desormes, who communicated it to the Academy of Sciences of Paris, on the 4th of December, 1826. He observes that "when steam is compressed in a boiler so that a strong current is made to blow out through a small orifice, a metal plate or disk, on being presented at a little distance from the

orifice, is forcibly repulsed; but if it is brought near, and pressed so as nearly to close the orifice and

Fig. 55.

cause the steam to escape in a star-like form around the outside of the disk in radiant directions, an ex-

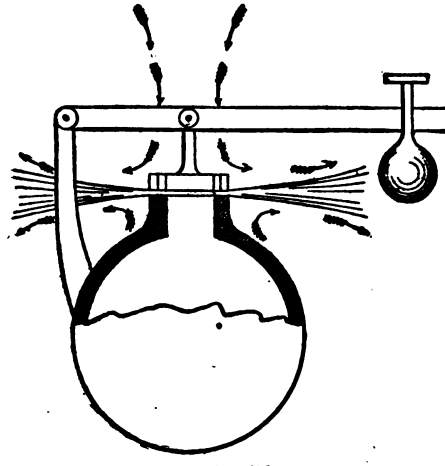


Fig. 56.

ternal pressure will be found to act upon the disk, and it can only be set at liberty by forcibly raising it."

On the facts observed by M. Desormes, Jacob Perkins makes the following remarks: "The steam forces off horizontally in every direction, as M. Desormes observes, in a star-like form. Now, as a strong current of air will be created by the velocity of the steam, and pass off with it, the surrounding air will follow, and in its course, as in Fig. 56, it will impinge on the disk and cause a pressure, and that in proportion to the hight or velocity of the steam. When the safety valve is so constructed—which is sometimes the case—as to allow the steam to pass off in a horizontal direction, the pressure will

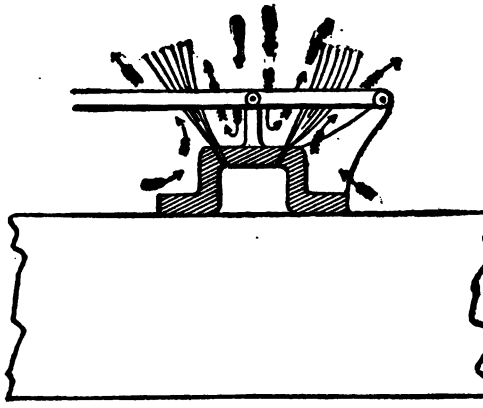


Fig. 57.

be greater than when the valve is conical, which gives a different direction to the steam, as in Fig. 57, making it more difficult for the air to impinge upon the valve."

The peculiar behavior of a ball placed within the influence of either a vertical or inclined jet, was noticed by Professor Leslie, of Edinburgh, in 1825, as already mentioned; and Professor Faraday delivered a lecture at the Royal Institution, some time between the years 1825 and 1829, in which the general action of jets upon the surrounding air, and, through this medium, upon balls and disks, was discussed. The "pneumatic paradox," in various forms, was illus-

trated in Vols. IX. and XI. of the London *Mechanics' Magazine*, for the years 1828 and 1829, and received the attention of Professor Hare and other writers in the early volumes of *Silliman's Journal* and the *Journal of the Franklin Institute*. In the second edition of "The Boy's Play-Book of Science," published in 1860, Professor Pepper, in speaking of currents of air that are dragged into an escaping jet of steam, says: "This tendency of the air to rush into a jet of steam, was discovered by Faraday, and explains those curious experiments with a jet of steam by

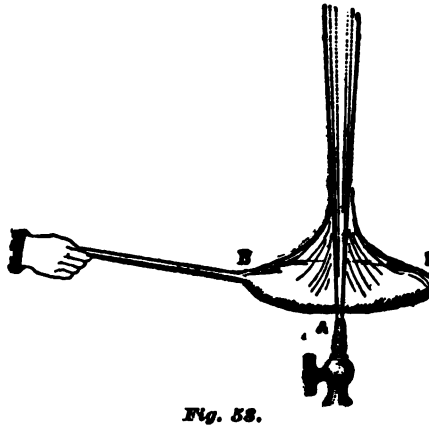


Fig. 58.

which balls, empty flasks, and globular vessels are sustained and supported either perpendicularly or horizontally. If steam, at a pressure of about 60 pounds per inch, is allowed to escape from a proper jet, and a large lighted circular torch, composed of tow dipped in turpentine, is held over it, the course of the external air is shown by the direction of the flames, which are forcibly pulled and blown into the jet of steam with a roaring noise, indicating the rapidity of the blast of air moving to the steam jet."

Fig. 58 shows a jet discharging high-pressure steam; B, B, lighted torch held around the escaping steam. The flames from the latter all rush into the former. Egg shells, empty flasks, India-rubber or

light copper and brass balls are suspended in the most singular manner inside an escaping jet of high-pressure steam, and before the explanation of Faraday reams of paper were used in the discussion of the possible theory to account for this effect; and

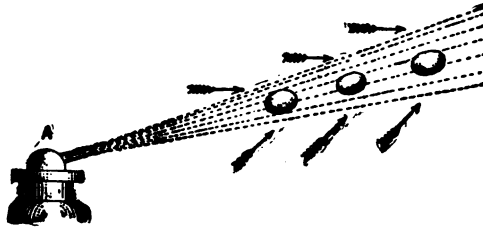


Fig. 59.

what made the explanation still more difficult, was the fact that the jet of steam might be inclined to any angle between the horizontal and the perpendicular, and still hold the ball, egg shell, or other spherical figure, firmly in its vapory grasp.

Fig. 60.

Fig. 59 is a ball-and-socket jet at an angle, and discharging steam. The egg-shells are supported by the enormous currents of air moving into the jet in the direction of the arrows.

In the latter part of the last century, the "principles of the lateral communication of motion in fluids" were investigated very thoroughly by Professor Ven-

turi, of Modena, and it is the action of the jet on the surrounding air, in accordance with the principles elucidated by him that the support of the ball in all cases depends. The peculiar action of "induced lateral currents" of air is well illustrated by a simple experiment: Take a piece of ordinary writing-paper, roll it around a common lead pencil, and confine its outer edge with paste or gum, and on withdrawing the pencil you have a paper tube. Cut

Fig. 61.

a circle of about 2½ inches across, out of a stiff card, and pierce its center with a hole about ¼ inch in diameter; now attach the paper tube to the center of the card by some sealing wax, and near the edge of the side opposite to that occupied by the tube, place three small drops of sealing wax at equal distances from each other; then cut another circle of card of the same size as the first; on putting this card on the drops of wax before named, inverting the whole apparatus, and blowing forcibly through the

tube, as shown in Fig. 60, it will be found to be impossible to displace the card, but as soon as the blast of air ceases the card will drop of itself; this is one form of the "pneumatic paradox" so called, and the support of the card is due entirely to the action of "lateral" or "induced currents" of air.

At the Centennial Exhibition at Philadelphia, in 1876, the curious phenomenon was shown of a ball sustained by an inclined current of air, which was shown in the exhibit of the Westinghouse Air-Brake Company. This company had a receiver filled with compressed air, at about 70 pounds pressure to the square inch. When the brake on exhibition was

Fig. 69.

not in operation, the air of the receiver, being continually supplied by an air pump, was allowed to escape through a nozzle of about ¼ inch bore, set to a vertical inclination of about 30°. Over this jet of air was placed a ball (see Fig. 61), which remains afloat in the air without any visible means of suspension. There were five balls;—first, a solid glass ball of 1¼ inch diameter; second, two solid wooden balls of 3 inches diameter; third, one hollow rubber ball of 3 inches diameter; fourth, one hollow rubber ball of 5 inches diameter. Each of the above balls, when placed in the air jet, showed this phenomenon.

Even more curious it appears when two balls are suspended simultaneously; the current of air, after

leaving the small glass ball, being sufficiently strong to give support to the largest (5 inches in diameter) of the rubber balls. The impression this experiment

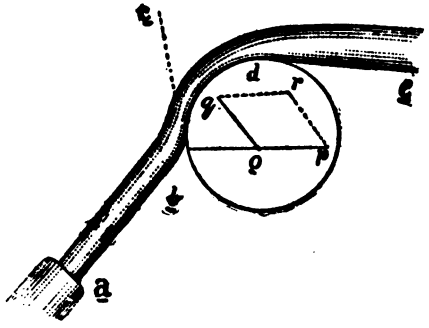


Fig. 63.

created was very striking indeed. As a rule, the suspended ball rotates very rapidly in the direction shown by the arrow, but sometimes it remains sta-

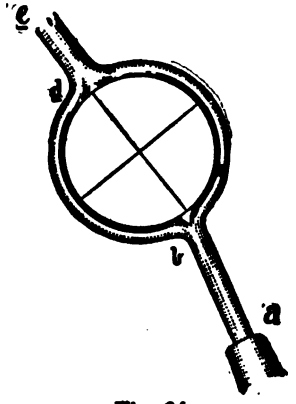


Fig. 64.

tionary, owing to the fact of the center of gravity not coinciding with the geometrical center: for the same ball once made to rotate by an external force, will continue the rotation with increased speed. The vertical inclination of the jet may be changed to

about 45° before the ball loses its state of suspension and drops off.

A similar phenomenon—a ball dancing on top of the water-jet of a fountain—is often seen, and will likewise remain sustained if the jet is more or less inclined (see Fig. 62).

Hugo Bilgram, mechanical engineer, of Philadelphia, makes the following explanation of the cause of that remarkable phenomenon: His investigation revealed the fact that the current *a b*, Fig. 63, instead of leaving the ball in the line *b c*, as might be expected, follows the curvature of the ball along the line *b d*, and at length leaves the ball in the line *d e*. A light ball, when placed in the jet, is struck

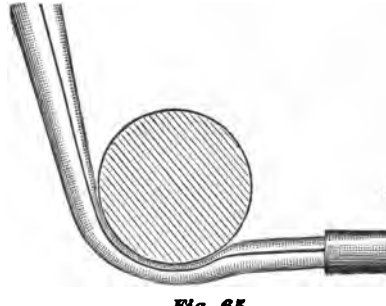


Fig. 65.

nearly centrally (see Fig. 64), the current envelops the whole ball and unites again, leaving the ball in the line *d e*, appearing as though the current was passing through the ball. It can however, easily be found that the upper branch of the current is stronger than the lower one.

By a series of subsequent experiments, it was found that any current of air striking a convex surface, has the tendency to follow that surface. One of these experiments is as follows: Attach to one end of a small tube, about ¼ inch to ½ inch diameter, and 4 to 6 inches long (which may be made by rolling up a piece of writing-paper), a piece of thread or yarn about 4 to 5 inches long. Blow through the other end of this tube and direct the current

against an object with a convex surface. The thread, following the current, will indicate a deflection as shown in Fig. 65. After demonstrating this fact, the next step was to find its cause. It is well known that any current tends to carry along with it the surrounding particles of air; hence, the supposed currents *b c*, Fig. 63, being freely supplied with air from the left side only, will create a rarefaction of air in the angle *c b d*. It is thus exposed to a one-sided pressure, and will, therefore, be deflected, as mentioned, and follow the curvature of the surface until it meets a counter-current sufficiently strong to prevent a further rarefaction. If this view can be substantiated, it is plain that two external forces are acting upon the ball. One, the impact of the air cur-

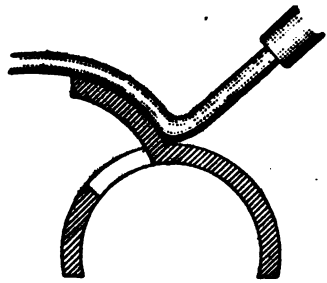


Fig. 66.

rent at *b*, transmitted at right angles to the surface, acts radially, and can be represented by the line *c p*. The other force, *c q*, is occasioned by the surplus pressure of the atmosphere on the lower side of the ball, over that of the rarefied zone under the curved current, and, combined with *c p*, it forms the vertical resultant *c r*, by which the weight of the ball is sustained. The rarefaction of air under the deflection current can be proved by the following experiments: Cut a small hole, say ¼ inch square, in a piece of cardboard, fasten over this hole a cover of the same material, by means of a strip of thin paper and mucilage, to form a valve, and bend both the card and the valve into cylindrical form. If, now, a current of air is

directed against the card, as shown in Fig. 66, the valve will open wide, showing the pressure under it to be greater than that above it. Or, take a strip of ordinary paper, about 1 to 2 inches wide, lay it over a cylindrical surface, and blow against it in a nearly tangential direction. The end of the strip will then rise as shown in Fig. 67.

Quite a number of other experiments might be mentioned, proving the same facts. The rotation of the ball is produced by the friction of the air currents passing over the ball, and is, therefore, a secondary result.

The phenomenon of deflection of a current when striking a convex surface can be brought to bear on

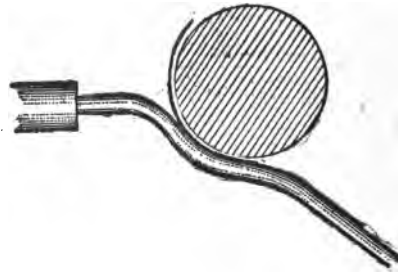


Fig. 67.

geographical and meteorological facts. The Gulf Stream follows the curved shore of the United States, for the identical reason that the aërial current follows the shape of a cylinder or a globe, and takes a course which otherwise it would not take. When a current of the higher strata of the atmosphere strikes the peak of a mountain, it will be deflected, follow the sides of the mountain, and will sweep the valley.

A TREACHEROUS SAFETY-VALVE.

Boilers are often operated without any steam gauge, depending on the safety valve only, to show the maximum steam pressure, a practice which should not be allowed under any circumstance. W. F.

Durfee relates the following circumstances which came under his experience, which shows the dangerous practice of using boilers with *one* safety valve only, also the hidden danger which may exist in an apparently reliable safety valve.

Mr. Durfee says: About twenty years ago, during the progress of some constructions then under my supervision, I procured a second-hand portable boiler for temporary use. This boiler was provided with a safety valve whose lever was graduated to 120 pounds, and three gauge cocks, but had neither pressure gauge nor glass water gauge, and, as the boiler was to be used but a short time, I did not think it necessary to furnish it with the two last-named fixtures.

The boiler was placed in the care of a steady-going son of Erin, whom we will call John, with instructions to leave the safety-valve weight on the 60-pound notch; to keep two gauges of water; to keep the steam as near 60 pounds as possible, and to report at once any trouble which occurred. John took a lively and attentive interest in his duties, and everything went well with him and the boiler for several weeks. But one day I was surprised by his sudden appearance, with every limb and feature indicative of extreme terror. As soon as he was able to speak, he exclaimed:

"The divil's got in the boiler, Mr. Durfee!"

"What do you mean, John?" said I.

"The divil's got in the boiler, I tell ye; fur the weight's on the ind av the liver, an' is up in the air as high's it can git; an' the divil a mite iv stame's comin' out!"

"Well," I replied, "we will go down and see if we can get the 'divil' out."

On reaching the boiler I was surprised to find the valve weight at the 120-pound notch, and that it *was* as high as it could "git" (Fig. 69), and, to my utter astonishment, there was but a suggestion of steam escaping. My first thought was that in all probability I was in the immediate vicinity of a boiler explosion; however, there was nothing to

do but to ascertain the cause of the existing conditions, and therefore I immediately tried the gauge cocks, found two full gauges of water, and, from the appearance of the steam which escaped on

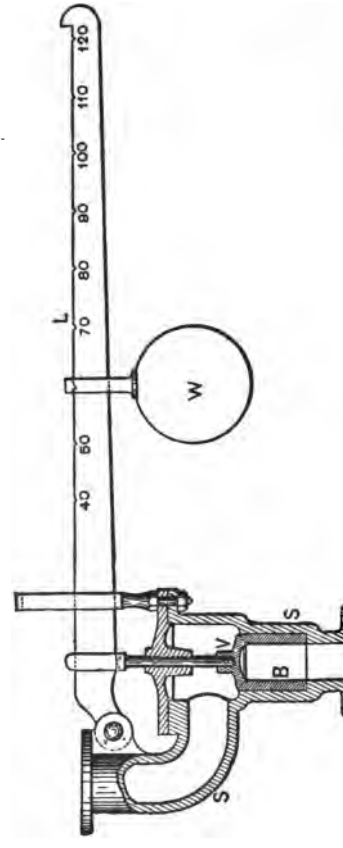


Fig. 68.—Valve before the Devil got into the Boiler.

opening the upper cock, it did not seem possible that there was 120 pounds pressure upon the boiler. I then took a fire-hook, and without much effort, pulled the safety-valve lever down, but on releasing the hook it slowly returned to its

former position, and at no point of its movement was there any increase of the very small and feeble volume of steam escaping. I repeated this experiment with the same result, and then began to think

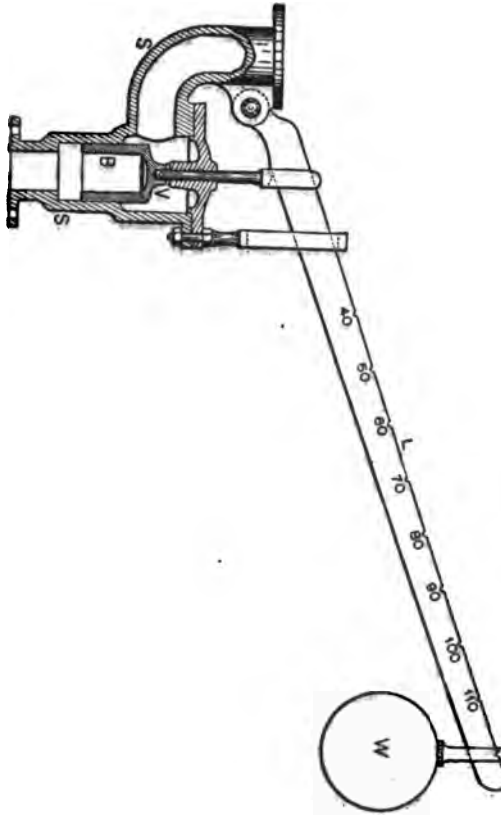


Fig. 69.—Valve after the Devil got into the Boiler.

that John's diagnosis was correct; the boiler certainly seemed to be "possessed of a devil." Just how he got in, and how he produced the observed effects, I could not imagine; my previous practical experience with steam machinery, which I had been in the habit of regarding as embracing every species of "pure cuss-

edness" that steam generators were heir to, did not furnish any clew to the mystery—for mystery it certainly appeared, and one which required prompt and decisive action for its solution. I therefore ordered John to draw the fire as quickly as possible, and to report to me when the boiler was cold enough for men to dismount the valve. In due time this was accomplished, and the state of facts disclosed is represented in the accompanying cuts (Figs. 68 and 69), which show the interior of the valve before and after it became "possessed of the devil" of deadly danger. The engravings so clearly exhibit the details of the valve and the relative position of its several parts that very little explanation is necessary, and it will suffice to say that the shell S of the valve was of cast iron, bored out to receive a cylindrical gun-metal bushing, B, which was forced into its place and held there simply by friction. On the upper end of this bushing the sit for the valve V was formed. As long as the bushing B remained immovable the steam pressure acted on a circular area of the lower surface of the valve V, having a diameter equal to that of the *interior* of the bushing B, but as soon as the repeated expansions and contractions incident to use and years had loosened the bushing B the circular area upon which the steam acted had a diameter equal to the *exterior* of the bushing B, which, with the valve V resting upon it, was then free to move upward (see Fig. 69) as far as the lever L would permit, acting simply as a piston valve—or, rather, piston—with no outlet for the steam save that due to the trifling leakage arising from its imperfect fit in the shell S. The area of the last named circle was a little more than *double* that of the first.

John's procedure before he reported the presence of the "divil" in the boiler, was as follows: Observing the lever L in the position indicated in Fig. 68, when the weight W was at the 60-pound notch, and desiring to ascertain what pressure there was on the boiler, he commenced moving the weight W outward, the pressure of his fear augmenting as he moved the weight from notch to notch until the end of the lever

was reached, and then the dynamic value of his terror was sufficient to send him flying to me as fast as his quaking legs could carrry him. It is not uncommon for a coroner's jury, while attempting to ascertain the cause of some disastrous boiler explosion, to be told by the confident witness (he is always on hand in strong force on such occasions) that "the safety valves were all right, as they had been examined but an hour before the explosion occurred." Such evidence in the case of a safety valve like the one I have described would be of no value whatever, as the fact of its being in good order when examined would be no assurance that within the next five minutes it would not be worse than no safety valve at all. It is extremely probable that there are many such safety valves in use to-day, and also that valves of such construction have been the cause of many unexplained explosions.

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